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A novel hybrid sustainable healthcare supply chain model for patient safety: A case study of Cambodia

Chayada Kanokphanvanich[1], Wanchai Rattanawong[2], Varin Vongmanee[3*]

[1]*Graduate School, University of the Thai Chamber of Commerce, Bangkok 10400, Thailand.*
[2,3]*School of Engineering, University of the Thai Chamber of Commerce, Bangkok 10400, Thailand.*

Corresponding Author: Varin Vongmanee (*Email: varin_von@utcc.ac.th*)

Abstract

This research focuses on elucidating the attributes of a Sustainable Healthcare Supply Chain (SHSC) that play a pivotal role in enhancing patient safety, particularly in developing nations. Patient safety in healthcare supply chains is paramount, particularly in the face of inherent risks and vulnerabilities associated with disruptions and uncertainties. A hybrid selection model, integrating factor analysis, structural equation modeling (SEM), and the Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), is introduced to rank these attributes. Twenty-two SHSC attributes are categorized into four facets: social, environmental, economic, and technological. A survey conducted across five Cambodian provinces gathered 361 valid responses from healthcare professionals, forming the basis for a structural SHSC model. This model is subsequently implemented in a Phnom Penh tertiary hospital. The findings underscore the imperative of incorporating patient safety considerations into healthcare supply chains. The hybrid selection model helps healthcare leaders figure out what factors are most important for patient safety and rank them. This gives them information they need to come up with effective strategies and long-lasting projects. The study's outcomes provide actionable insights for healthcare stakeholders. The multi-analytical approach of the model offers a comprehensive perspective to address supply chain challenges, reduce extraneous costs, and minimize environmental footprints. In essence, the effective implementation of sustainable healthcare supply chain strategies not only enhances care quality and fortifies patient safety but also aligns with the broader objectives of healthcare entities.

Keywords: Fuzzy TOPSIS, Healthcare management, Healthcare supply chain, Patient safety, SEM, Sustainability, Technology.

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1. Introduction

In recent years, the notion of sustainability has garnered considerable attention across various sectors, including the healthcare industry. The United Nations General Assembly has delineated sustainable development as a multifaceted concept encompassing social, economic, and environmental dimensions [1]. Aligned with this, the 2030 Agenda for Sustainable Development outlines 17 Sustainable Development Goals (SDGs), seeking to eradicate poverty and hunger, foster prosperity for all individuals, and promote a peaceful and safe planet [2]. However, the onset of the global COVID-19 pandemic in early 2020, declared a public health emergency by the World Health Organization (WHO) [3], has had far-reaching repercussions. These repercussions include a high mortality rate, physical and psychological impacts, and economic deceleration [4]. Furthermore, the pandemic has disrupted global supply chains, significantly affecting the healthcare sector. Consequently, the scarcity of essential medicines, critical drugs, vaccines, medical supplies, and equipment has been exacerbated [5]. Moreover, the healthcare industry is confronting the challenge of meeting surging demands while minimizing social and environmental consequences [6]. Given these concerns, researchers, experts, managers, and policymakers within the healthcare industry have placed substantial emphasis on investigating and implementing a sustainable healthcare supply chain (SHSC) to prepare for future uncertainties. The aforementioned concerns have been raised across the globe, especially in developing countries, which have experienced the most impact from these uncertainties.

Cambodia is a developing country that has demonstrated consistent advancements in its healthcare sector in recent years, manifesting in the reduction of child mortality rates, improvement in maternal health, and a decline in the prevalence of communicable diseases such as HIV, tuberculosis, and malaria [7-9]. Additionally, the Cambodian government has made commendable progress in collaboration with the United Nations towards achieving the Sustainable Development Goals (SDGs) by 2030 [10]. The World Bank also recognized Cambodia′s transition from a low-income to a low-middle-income country in 2016, attributable to substantial growth in gross domestic product and a significant reduction in poverty rates [11]. Nevertheless, these admirable accomplishments, the COVID-10 pandemic has had a significant impact on Cambodia, as it has on other developing countries [12, 13]. Challenges include limited access to healthcare, a lack of medical equipment, and shortage of hospital facilities and healthcare workers. The healthcare supply chain (HSC) in Cambodia faces unique challenges due to the country's socio-economic conditions and infrastructure limitations [14]. The procurement and sourcing of healthcare products are key challenges in Cambodia. The majority of pharmaceuticals and medical supplies are imported, making them vulnerable to supply chain disruptions [14]. The prevailing global uncertainties, exacerbated by the pandemic, have unequivocally highlighted the fragility of the HSC in Cambodia. Consequently, significant attention to and prioritization of the strengthening of the HSC in the country and the implementation of the concept of SHSC to manage future uncertainties are essential.

This research builds upon the previous work by Kanokphanvanich, et al. [15], which introduced a conceptual model of SHSC with a primary focus on enhancing patient safety from the perspective of healthcare workers, who are one of the key stakeholders in the HSC [15]. Existing literature frequently touches on the three pillars of sustainability. However, comprehensive discourse on their cohesive integration appears sparse. Numerous publications have emerged addressing technologies introduced during the pandemic. Yet, a limited few have melded this technology into a sustainability model for HSC with a specific focus on patient safety. This research adopts the conceptual framework proposed by Kanokphanvanich, et al. [15], which distinctively integrates technology alongside the traditional three pillars of sustainability. Such technologies are increasingly recognized as pivotal drivers in adapting to the "new normal" in the post-pandemic era. This integrated approach not only reinforces the triple bottom line but also accentuates the importance of patient safety. The proposed SHSC model encompasses four dimensions, namely social, environment, economic, and technology, presenting a total of 22 attributes derived through a fuzzy Delphi approach. However, the previous research solely presented a conceptual framework, lacking practical application to real-world scenarios. Hence, it is crucial to address the existing gaps and limitations in order to facilitate the implementation of SHSC. With this aim in mind, this research adopted the following objectives:

1. To conduct a comprehensive review and refine the attributes using exploratory factor analysis (EFA).
2. To design and propose a novel model using structural equation modeling for SHSC that prioritizes patient safety from the perspective of healthcare workers, who are one of the key stakeholders in HSC.
3. To empirically test the formulated hypotheses and validate the structural model by collecting data from healthcare workers (HCWs) focused on doctors, nurses, pharmacists, and other professionals, including radiologic technologists and laboratory technologists who work in clinics and hospitals in Cambodia.
4. To prioritize the attributes of SHSC through the application of Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) in a real-world case. This prioritization aimed to assist organizations in selecting the most crucial attribute to implement sustainable strategies.

This research provides significant contributions in the following areas:

- Validation of the SHSC model, which incorporates a novel pillar of technology alongside the three conventional pillars of sustainability. This integration will enhance the comprehensiveness and applicability of the SHSC framework.
- Provision of a valuable assessment tool for healthcare organizations to evaluate their contextual factors and identify the most crucial attribute to formulate effective strategies for the implementation of SHSC. This assessment will enable organizations to prioritize patient safety as the ultimate goal of healthcare service.

The subsequent sections of this article are structured as follows: Section 2 comprises the literature review and hypothesis development relevant to the current study. Section 3 outlines the research methodology adopted for this study.

Section 4 presents the research findings and their practical application in a real-world case. Section 5 engages in a discussion of the obtained research results. Finally, Section 6 encompasses the conclusion, limitations of the study, and opportunities for future research.

2. Literature Review and Hypothesis Development

2.1. Sustainable Healthcare Supply Chain (SHSC)

Sustainable supply chain in healthcare is a systematic approach to managing the distribution, procurement, production, and logistics of healthcare goods and services. It refers to the efficient, cost-effective flow of resources including materials, information, and finance, amongst a network of organizations. While aiming to meet the immediate needs of patients and healthcare institutions, the approach also seeks to minimize its impact on economic, environmental, and social well-being, ensuring responsibility and resilience for the betterment of its last-mile users over the long term [15, 16]. Incorporating the principles of sustainability within the HSC necessitates that organizations actively reduce the consumption of both renewable and non-renewable resources while simultaneously seeking out environmentally friendly solutions through supply chain enhancements [16]. The integration of sustainability principles within the healthcare supply chain has gained significant momentum in response to the institutionalization of the United Nations Sustainable Development Goals (SDGs) as part of the UN 2030 Agenda. The SDGs, which United Nations introduced in 2015, have a wide range of goals, including the eradication of poverty, ensuring food security, enhancing healthcare and education, promoting gender equality, providing access to clean water and sanitation, encouraging to use of renewable energy, fostering economic prosperity and decent work, supporting sustainable industry and innovation, reducing inequalities, developing sustainable cities and communities, and promoting [1, 16, 17]. The definition of HSC can be described as an interconnected system comprising various functions that facilitate the movement of medicines, vaccines, medical supplies, equipment, and consumables. This system enables the delivery of these resources to clinical service providers, who in turn provide healthcare services to end-users, namely patients [15].

Patient safety, in relation to a sustainable healthcare supply chain, is the proactive approach to ensuring that all medical products, equipment, and services sourced, produced, and delivered throughout the chain consistently meet rigorous safety and quality standards. This not only protects patients from harm but also aligns with environmental, social, and economic sustainability principles, ensuring the longevity and reliability of healthcare delivery for present and future generations [6, 15]. Ensuring a patient's safety serves as a foundational prerequisite upon which other healthcare objectives are built. While quality of care, patient experience, and optimized patient outcomes are undeniably vital, they inherently depend on a patient-first safety approach. For example, without the assurance of safety, even high-quality care may not achieve its intended benefits, and the patient experience can be negatively impacted. However, healthcare provision is multifaceted, and its objectives are intertwined. Patient safety, quality of care, and patient experience are interrelated elements that collectively contribute to the broader impact of healthcare on individuals, communities, and society [18, 19]. The emergence of the COVID-19 pandemic and other instances of uncertainty have underscored the imperative of establishing an agile, adaptable, and robust supply chain system capable of sustaining economic and social progress in a sustainable manner [20].

When organizations embrace supply chain management as a strategic approach, the importance of implementing sustainable inputs within their supply chain strategies becomes even more pronounced [21]. Technology has emerged as a significant factor in the healthcare industry, playing a pivotal role in enhancing business competitiveness and enabling organizations to effectively address the challenges posed by ongoing uncertainties [22]. There are various studies discussing the benefits of technology related to patient and practitioner safety and environmental and economic sustainability. Numerous studies have examined the advantages of incorporating technology in healthcare, particularly in relation to enhancing patient and practitioner safety [21, 23], as well as promoting environmental and economic sustainability [24, 25]. While many articles have addressed the benefits of technology in the context of sustainability across these three pillars, only a limited number of studies have integrated technology into the specific sustainability dimensions. Furthermore, none of these studies have conducted empirical research to validate the proposed models [15, 26]. The present study proposes an empirical test to validate the structural model by collecting data from healthcare workers in Cambodia.

2.2. Social Sustainability

Within the healthcare setting, the social system is intricate and involves a multitude of stakeholders [27]. The preceding study emphasized the comprehensive nature of social sustainability within the supply chain, covering essential dimensions such as health and well-being, equality, safety, morality, and human rights [28, 29]. The global pandemic and other uncertainties have exposed the fragility of global supply chain sustainability, impacting developing countries and exacerbating their social vulnerabilities in times of economic downturn [30]. Scholars have extensively examined a multitude of articles, aiming to identify the drivers, challenges, barriers, tensions, practices, and performance factors associated with social sustainability within supply chains [31]. Social sustainability entails minimizing social exclusion and promoting social equity, thereby ensuring equal access to healthcare for individuals within the community and addressing their diverse needs [32]. The complexity of social sustainability within the supply chain necessitates a clear understanding and analysis by healthcare organizations [28]. To effectively comprehend and address social sustainability, organizations must identify the key stakeholders responsible for social responsibility and involvement. Additionally, it is crucial to identify the pertinent issues that require attention and to develop appropriate strategies for fostering sustainability within the healthcare supply chain.

2.3. Environmental Sustainability

Human activities have contributed to a growing environmental vulnerability, leading to ecosystem degradation that significantly impacts human health and well-being. To mitigate the adverse effects, it is imperative to assess the potential consequences of environmental vulnerability and develop adaptation strategies, policies, and measures [33]. The healthcare sector has demonstrated a notable negative impact on the environment, which was particularly evident in the significant increase in medical waste during the pandemic outbreak. Widespread usage of single-use face masks, surgical gloves, and sanitizers resulted in the generation of substantial medical waste and environmental pollution [34]. In the United States, the healthcare sector is responsible for approximately 10% of total carbon emissions. Given the significant energy consumption of radiology equipment and the waste produced during interventional procedures, radiology emerges as a prominent factor in contributing to these environmental challenges. To tackle this issue, healthcare facilities should integrate sustainability as a crucial performance indicator and establish a framework that enables radiologists to actively participate in reducing their carbon footprint. This can be achieved through quality improvement initiatives and fostering collaboration among stakeholders [35]. Notably, the measurement of environmental performance heavily relies on the organization’s environmental strategy, and there is evidence that internal stakeholders recognize the role of environmental performance in satisfying external stakeholders. It is evident that healthcare services need to demonstrate value creation across various dimensions [36].

2.4. Economic Sustainability

Sustainable supply chain management (SSCM) within the economic pillar aims to enhance the cost-efficiency and effectiveness of supply chains while concurrently ensuring environmental and social considerations are not compromised [37]. The concept of value-based healthcare emphasizes the importance of resource allocation based on need and optimal utilization to serve those in need. Thus, delivering economic value to customers in healthcare services should not be disregarded [38]. Healthcare supply chain managers face the ongoing challenge of balancing the costs of risk mitigation with the costs and losses incurred by these risks. It is crucial for managers to recognize that minimizing costs should not lead to compromised patient care Senna, et al. [39]. Swarnakar, et al. [40] proposed the successful deployment of the Lean Six Sigma framework to enhance service quality in healthcare organizations. This framework aims to reduce patient lead time and process cycle time and improve sustainability by minimizing costs, optimizing resources, and reducing waste Swarnakar, et al. [40]. In developing nations, the lack of flexibility, uncertainty of the economic environment, and the absence of institutional frameworks hinder the understanding of real issues within the supply chain, creating barriers to innovation [16]. Additionally, the growing demand for high-quality healthcare in developed countries has led to limited resources, making social marketing an effective tool for promoting sustainable behavioral change [41].

2.5. Technology in the Healthcare Supply Chain

Technology plays a vital role in the healthcare industry, particularly in ensuring sustainable business growth amidst strong competition [42]. As previously highlighted, the healthcare supply chain serves as the backbone of the industry, making efficient supply chain management crucial for gaining a competitive advantage [43]. Hospitals, as significant buyers in healthcare, possess substantial purchasing power that can drive industry-wide changes. Scholars have increasingly focused on technology-enabled supply chain management in the healthcare industry to enhance efficiency and effectiveness [22, 44]. The COVID-19 pandemic exposed various challenges, including shortages of healthcare tools, limited testing capacities, inadequate medical essentials, insufficient personal protective equipment (PPE) kits, and inadequate training and safety measures for healthcare workers (HCWs). Policymakers must address these challenges promptly to prevent infections among HCWs. Technology utilization, such as Blockchain, IoT, AI, Drones, Robots, and automated sanitization, can minimize direct intervention by HCWs at various stages, thereby reducing the risk of HCW contamination [45, 46]. The analysis of the literature and identified challenges highlighted infrastructure deficiencies, a shortage of HCWs, a lack of availability of medical essentials, and inadequate technological support as major issues faced by healthcare organizations during the pandemic [45].

Patient safety is a critical concern in healthcare, as improper patient or drug identification can lead to an increasing number of medical errors. Integrated IT infrastructures are believed to prevent most preventable medical errors caused by misidentifications. Radio Frequency Identification (RFID) technology is considered the next-generation tracking and data-collection solution in the healthcare industry [47-49]. Blockchain technology has also gained prominence in various domains, including supply chain management, where it facilitates the creation and maintenance of immutable histories of business objects. In healthcare, it aids in controlling drug lifecycles and preventing medication prescription counterfeiting. Additionally, blockchain technology is utilized in the back-end systems of cryptocurrencies such as Bitcoin and Ethereum [50]. Previous research has shown that technology reduces manual record-keeping errors, ensures timely decision-making, and minimizes mistakes. Technologies such as the Internet of Things (IoT) and Artificial Intelligence (AI) in medical devices and networks increased intelligence and efficiency during the COVID-19 pandemic [50, 51]. These technologies provide rapid information and communication, enhancing patient quality of life. In the future, such technologies will improve patient health, contribute to better treatments, and be valuable in managing future pandemics or uncertainties.

Previous research has acknowledged that hospital supply chains often face economic, environmental, and social challenges [52]. Consequently, it is believed that healthcare organizations, by taking responsibility for environmental and social issues such as pollution and unacceptable working conditions, can mitigate adverse effects while contributing to economic development and promoting sustainability within the healthcare supply chain (HSC) [43].

Several studies have explored the interconnectedness of the three pillars of sustainability and technology. They highlight the advantages of elastomeric face masks as a safer and more sustainable alternative to the reuse of disposable N-95 masks during the COVID-19 outbreak. This approach promotes socio-environmental sustainability by saving lives, reducing material and resource usage, and minimizing waste, thus benefiting both the environment and society [53, 54]. found a relationship between environmentally sustainable practices and the financial performance of firms. The results indicated that innovation and waste reduction are two important criteria that enable firms to benefit from environmentally sustainable practices. Additionally, factors within the social dimension, such as healthcare workers' well-being, employee engagement, and strong stakeholder engagement with the community, were shown to improve HSC performance by reducing unnecessary costs and promoting economic sustainability Banerjee, et al. [54]. Chandra, et al. [22] also noted that the social sustainability dimension has great importance in healthcare organizations as it contributes to the delivery of sustainable health services, leading to improved health outcomes and reducing unnecessary costs. When employees are satisfied with factors such as their health, training, and wages, they tend to develop stronger job engagement and perform at a higher level Chandra and Kumar [43]. Furthermore, several studies have explored the interconnectedness of technology with sustainability in healthcare. For instance, Mukati, et al. [55] discussed the adoption of technology in the healthcare sector, emphasizing its potential to enhance the intelligence, transparency, and efficiency of medical devices and networks, ultimately improving the quality of life for patients [55]. Similarly, technologies like IoTs enable digitalization and effective management of medical procedures while also providing insights into public health concerns such as climate change and environmental impact monitoring Kumar, et al. [45]. Bialas, et al. [44] presented a holistic conceptual framework that categorizes technology-driven supply chain management in healthcare based on its environmental, economic, and social characteristics [44].

It is evident that the four dimensions of sustainability can mutually support and enhance the healthcare supply chain in a sustainable manner. Given the importance of these dimensions and their interrelationships, this research proposes the following hypotheses, presented in Table 1

Table 1.
The summary of research hypotheses.

Hypotheses	Detail
H1	The sustainable healthcare supply chain model that prioritizes patient safety aligns with the empirical data
H2	The social dimension is a significant component of the SHSC
H3	The environmental dimension is a significant component of the SHSC
H4	The economic dimension is a significant component of the SHSC
H5	The technology dimension is a significant component of the SHSC
H6	The social dimension correlates with the technology dimension for ensuring patient safety in SHSC
H7	The environmental dimension correlates with the technology dimension for ensuring patient safety in SHSC
H8	The economic dimension correlates with the technology dimension for ensuring patient safety in SHSC
H9	The social dimension correlates with the economic dimension for ensuring patient safety in SHSC
H10	The economic dimension correlates with the environmental dimension for ensuring patient safety in SHSC
H11	The social dimension correlates with the environmental dimension for ensuring patient safety in SHSC

3. Research Methodology

This study employed a mixed-methods approach to accomplish its research objectives. The primary objective of the study was to comprehend the significance of attributes related to SHSC and propose a novel SHSC model that places a high priority on patient safety, which is the ultimate goal of healthcare. To validate and test the hypotheses, the study utilized a hybrid approach incorporating Structural Equation Modeling (SEM). Furthermore, the study employed Fuzzy TOPSIS, a multi-criteria decision-making technique, to prioritize the importance of attributes in a real-world scenario. This approach aided in the selection of the most critical attributes for organizational strategies.

3.1. Measurement

This study builds upon the previous research conducted by Kanokphanvanich, et al. [15]. The variables examined in this study were derived from the finalized outcomes of the conceptual model of the Sustainable Healthcare Supply Chain (SHSC) proposed in the previous study. The conceptual model consists of four dimensions and 22 attributes of SHSC, as detailed in Appendix A. The variables used in this study were determined through a Fuzzy Delphi method, involving the input of 13 experts in the context of developing countries [15].

3.2. Questionnaire Design and Distribution

The questionnaire was designed based on the identified 22 attributes of SHSC and translated into English and Khmer, the most common languages used in Cambodia. A web-based semi-structured format for disseminating the questionnaire. To ensure privacy and distinguish between participants, the system assigns a unique code ID to each respondent. This code ID system maintains respondent anonymity while guaranteeing a one-to-one correspondence (one person, one code ID) to prevent duplicate responses.

The questionnaire was divided into two parts. The first part contained questions about the respondents' demographics. In the second part, the respondents were asked to evaluate the importance of SHSC attributes. Each question was answered on a 5-point Likert scale (1—not important, 2—slightly important, 3—moderately important, 4—V=very important, and 5—extremely important).

A survey was conducted in five major states of Cambodia, namely Phnom Penh, Siem Reap, Koh Khong, Preah Sihanouk, and Battambong, based on the density of number of the registered doctors [52]. As this study explored SHSC, which prioritizes patient safety from the perspective of healthcare workers, the data collection focused on doctors, nurses, pharmacists, and other professionals, including radiologic technologists and laboratory technologists. This study employed an online questionnaire from April 1, 2023 to May 31, 2023. The survey link was distributed to 500 respondents by the professional healthcare practitioners' network of the author team via email, LinkedIn, WhatsApp, and Telegram. The snowball sampling technique was used for data collection. A total of 361 valid responses were received, yielding a response rate of 72.2%. The demographic characteristics of respondents are presented in Table 2.

Table 2.
Demographic characteristic.

Item	Frequency	Percentage
Gender		
Male	184	51.0
Female	177	49.0
Age		
21–29 years	74	20.5
30–39 years	157	43.5
30–39 years	41	11.4
40–49 years	63	17.5
50–59 years	21	5.8
60 years old or older	5	1.4
Profession		
Medical doctor	161	44.6
Nurse	95	26.3
Other professional	92	25.5
Pharmacist	13	3.6
Years of experience		
Less than 5 years	45	12.5
5–10 years	143	39.6
11–15 years	122	33.8
16–20 years	34	9.4
More than 20 years	17	4.7
Type of work facility		
Public hospital or clinic	164	45.4
Private hospital or clinic	197	54.6
Province		
Phnom Penh	210	58.2
Siem Reap	80	22.2
Koh Kong	41	11.3
Preah Sihanouk	23	6.4
Battambong	7	1.9

3.3. Data Analyses
3.3.1. Structural Equation Modeling (SEM)

This study applied structural equation modeling (SEM) to present a novel model that illustrates the importance of SHSC prioritizing patient safety. The SEM technique offers a comprehensive approach for modeling variables, conducting goodness-of-fit tests, and assessing overall model validity, thereby facilitating model validation. Notably, SEM is particularly valuable for testing hypotheses in complex models involving a multitude of variables and relationships. Numerous researchers have extensively utilized SEM in the healthcare sector, as evidenced by prior studies [56-69]. For example, Chandra, et al. [22] applied SEM to assess key performance indicators in the vaccine supply chain′s impact on sustainable development [43]. Similarly, Ma, et al. [57] employed SEM to examine the influence of digital transformation on the performance of the pharmaceutical sustainable supply chain, while also exploring the mediating roles of information sharing and traceability [57]. Given the aforementioned benefits and the widespread application of SEM in healthcare, the authors of this study adopted SEM as the methodology for modeling, analyzing the collected data, and testing the proposed hypotheses. Through SEM, the present study aimed to identify and verify causal relationships among the variables within the proposed conceptual model.

3.3.2. Fuzzy TOPSIS

This study employed Fuzzy TOPSIS to assess and rank the most significant attributes of the Sustainable Healthcare Supply Chain (SHSC) in a hospital case study conducted in Cambodia. Fuzzy TOPSIS stands as a leading method for pinpointing the optimal solution among similar options. Additionally, it is favored for streamlining processes and reducing uncertainty and vagueness in the chosen criteria [62, 63]. Hwang and Yoon developed TOPSIS as a multiple criteria decision-making (MCDM) technique in 1981 [70]. Later, Chen and Hwang [71] introduced and integrated the fuzzy technique. Fuzzy TOPSIS has proven to be an effective technique for ad-dressing multiple criteria, as it incorporates fuzzy set theory to handle the inherent ambiguity in subjective judgments made by decision-makers, which often involve linguistic terms, satisfaction degrees, and importance levels that may be imprecise [67, 72]. This method encompasses the following steps:

Step 1: The decision-making group (DMs) consisting of hospital stakeholders of a healthcare facility in Cambodia was selected to evaluate the importance of SHSC attributes. A five-point scale was utilized in this study, enabling decision-makers to provide their judgments. Triangular fuzzy numbers (TFNs) were employed to represent the imprecision associated with these assessments, and Table 3 presents the TFNs utilized in the evaluation process.

Table 3.
Linguistic scale for evaluating SHSC attributes of alternatives and criteria.

Linguistic scale for rating	Abbreviation	TFNs
Not important	NI	(0,1,3)
Slightly important	SI	(1,3,5)
Moderately important	MI	(3,5,7)
Very important	VI	(5,7,9)
Extremely important	EI	(7,9,9)

TFN Ã is defined as (*a*,*b*,*c*), where *a* indicates the smallest potential value, *b* indicates the average possible value, and *c* indicates the largest potential value. The membership function $\mu_{\tilde{A}}(x)$ of Ã is described as follows:

$$\mu(x) = \begin{cases} 0 & x < a, x > c \\ \frac{x-1}{b-1} & a \leq x \leq c \\ \frac{c-x}{c-b} & b \leq x \leq a \end{cases} \quad (1)$$

The decision-makers, DMs(s = 1, …, p), used the linguistic scales to rank the significance of 22 HSHC attributes in accordance with n criteria. The relative weight vector of the criteria was defined as W = (w_1, w_2, …, w_n). The higher the rating, the more important the attribute. The initial assessment scores given by decision makers were aggregated and shown as the fuzzy decision matrix D˜s given by Equation 2:

$$\tilde{D}_s = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \vdots & & \ddots & \vdots \\ \tilde{x}_{k1} & & \cdots & \tilde{x}_{kn} \end{bmatrix} \quad (2)$$

Step 2: The fuzzy decision matrix was normalized using a linear transformation. The normalized fuzzy decision matrix $\tilde{T}$was obtained using the equations following:

$$\tilde{\boldsymbol{T}} = [\tilde{\boldsymbol{t}}_{ij}]_{k \times n}, i = 1, 2, .., k; j = 1, 2, \ldots, n (3)$$

Where

$$\tilde{\boldsymbol{t}}_{ij} = \left(\frac{a_{ij}}{C_j^*}, \frac{b_{ij}}{C_j^*}, \frac{c_{ij}}{C_j^*}\right), \boldsymbol{a} = \min_k\{\boldsymbol{a}_k\}, \boldsymbol{b} = \frac{1}{k}\sum_{k=1}^{k} \boldsymbol{b}_k, \boldsymbol{c} = \max_k\{\boldsymbol{c}_k\} \quad (4)$$

and

$$C_j^* = \max\{c_{ij}\} \ldots \text{importance criteria} \quad (5)$$

Step 3: The weighted normalization matrix $\widetilde{Y})$ was then calculated using the following equation:

$$\tilde{\boldsymbol{Y}} = [\tilde{y}_{ij}]_{k \times n} = [\tilde{\boldsymbol{t}}_{ij} \times \boldsymbol{w}_j]_{k \times n}, i = 1, 2, .., k; j = 1, 2, \ldots, n \quad (6)$$

Step 4: The fuzzy positive ideal solution (FPISA^+,) and fuzzy negative ideal solution (FNIS, A^-) for the SHSC could be calculated as follows:

$$A^+ = (\tilde{y}_1^+, \tilde{y}_2^+, \ldots, \tilde{y}_n^+) \quad (7)$$

$$\boldsymbol{A}^- = (\tilde{\boldsymbol{y}}_1^-, \tilde{\boldsymbol{y}}_2^-, \ldots, \tilde{\boldsymbol{y}}_n^-)(8)$$

Where $\tilde{\boldsymbol{y}}_1^+ = \max_i\{\tilde{\boldsymbol{y}}_{ij}\}$, and $\tilde{\boldsymbol{y}}_1^- = \min_i\{\tilde{\boldsymbol{y}}_{ij}\}$, $i = 1, 2, .., k; j = 1, 2, \ldots, n$

Step 5: The distance of each alternative from FPIS $(d_i^+)$and FNIS (d_i^-) was computed as follows:

$$d_i^+ = \sum_{j=1}^{n} d_y = \tilde{y}_{ij}, \tilde{y}_{1j}^+ \quad (9)$$

$$d_i^- = \sum_{j=1}^{n} d_y = \tilde{y}_{ij}, \tilde{y}_{1j}^- \quad (10)$$

$$d(\tilde{r}, \tilde{s}) = \sqrt{\frac{1}{3}(a_r - a_s)^2 + (b_r - b_s)^2 + (c_r - c_s)^2} \quad (11)$$

Step 6: The closeness coefficient $CC_i$of each SHSC attribute was computed as follows:

$$CC_i = \frac{d_i^-}{d_i^+ + d_i^-} \quad (12)$$

Step 7: The 22 SHSC attributes that prioritize patient safety from the perspective of healthcare workers were ranked. The most important attribute was closest to the FPIS and farthest from the FNIS

4. Results

4.1. Common Method Bias

According to Podsakoff, et al. [73], the presence of common method bias is a concern when a single respondent's responses account for over 50% of the total variance in the measures, as determined through exploratory factor analysis [73]. To address this potential issue, Harman's single-factor technique was employed, using SPSS 29.0 for the extracted factors representing the four latent constructs [74]. The findings showed that the maximum variance that a single factor could explain was 37.802%, which is less than predetermined cutoff value of 50%. Consequently, common method bias was not deemed a significant concern in this study.

4.2. Reliability and Validity Analysis

Factor and reliability analyses were conducted using SPSS 29.0 and AMOS 26.0.

4.2.1. Exploratory Factor Analysis (EFA)

This study employed Exploratory Factor Analysis (EFA) using the Principal Component Method (PCM) with Varimax rotation to categorize the 22 variables into four components, each with a minimum eigenvalue of 1.0. The Kaiser-Meyer-Olkin (KMO) test, with a desirable value of 0.50, yielded a highly suitable KMO value of 0.913 for factor analysis. Factor loadings exceeding 0.50 affirmed the strong association of each item with its latent variable. The four latent variables explained 64.714% of the total variance, indicating their substantial coverage of data variances. Cronbach's alpha values were computed for data reliability, with values above 0.70 considered internally consistent. Results, including factor loadings and internal consistency, are detailed in Table 4.

Table 4.
Factor loadings and reliability of SHSC attributes by EFA.

Construct	Attributes	Factor loadings	Cronbach's α
Social	SC1	0.834	0.859
	SC2	0.735	
	SC3	0.660	
	SC4	0.666	
	SC5	0.750	
	SC6	0.742	
	SC7	0.805	
	SC8	0.776	
Environment	EV1	0.739	0.805
	EV2	0.863	
	EV3	0.834	
	EV4	0.736	
Economic	EC1	0.641	0.809
	EC2	0.780	
	EC3	0.719	
	EC4	0.803	
	EC5	0.687	
	EC6	0.683	
Technology	TE1	0.816	0.811
	TE2	0.832	
	TE3	0.821	
	TE4	0.746	

Note: SC = Social, EV = Environment, EC = Economic, TE = Technology.

4.2.2. Confirmatory Factor Analysis (CFA)

Confirmatory Factor Analysis (CFA) was conducted as a method to analyze the measurement model based on the results obtained from the Exploratory Factor Analysis (EFA). The theoretical relationships identified through EFA were used to develop a measurement model in AMOS 26.0, as depicted in Figure 1.

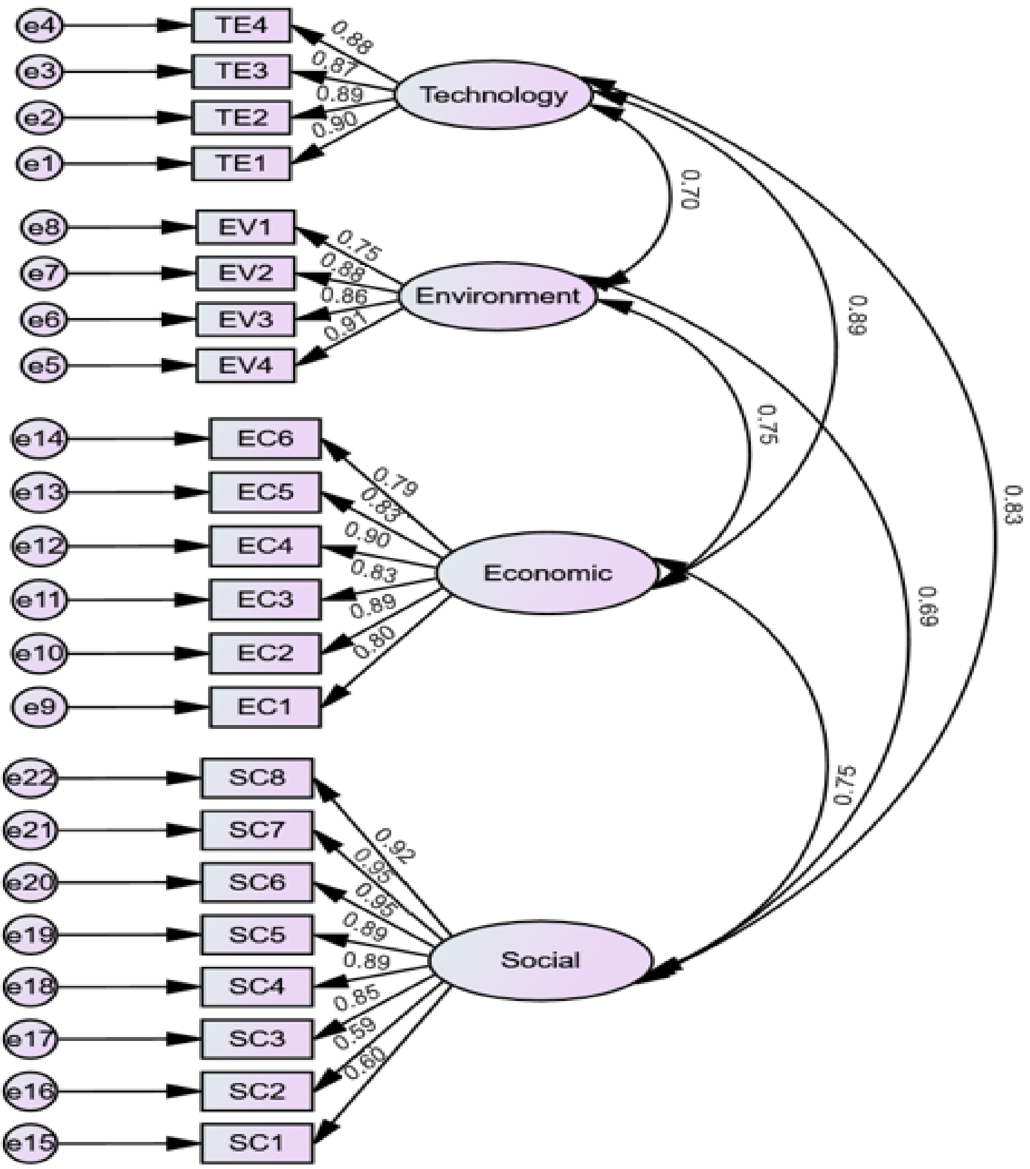

Figure 1.
Measurement model of SHSC.

Table 5 presents the findings of the CFA, which estimated the reliability of each construct using three indices: composite reliability (CR), average variance extracted (AVE), and Cronbach's alpha. The recommended threshold values for CR, AVE, and Cronbach's alpha are typically 0.70, 0.50, and 0.70, respectively [75-77]. Additionally, discriminant validity was assessed by comparing the square root of AVE with the correlation coefficients among the constructs. The results indicated that the square root of each construct exceeded the correlation coefficient with other variables, meeting the necessary requirements. This outcome demonstrated that the model employed in this study exhibited satisfactory discriminant validity.

Table 5.
Reliability, discriminant validity, and correlation coefficients in CFA.

Construct	Cronbach's α	CR	AVE	SOC	ENV	ECO	TEC
SOC	0.859	0.910	0.560	0.748			
ENV	0.805	0.872	0.632	0.425	0.795		
ECO	0.809	0.866	0.520	0.594	0.529	0.721	
TEC	0.811	0.880	0.647	0.646	0.373	0.685	0.804

Note: SOC = Social, ENV = Environmental, ECO = Economic, TEC = Technology. The diagonal numbers represent the square root of average variance extracted (AVE) for each construct.

4.3. Structural Equation Model and Hypothesis Testing

In order to better understand the overarching structural structure of the SHSC, a second-order confirmatory factor analysis was employed. In this study, the higher-order latent variables are SHSC, while the first-order latent variables, are the four aforementioned constructs. Each first-order latent variable is indicated by multiple observed variables. The second-order confirmatory factor analysis model is presented in Figure 2. The model was tested based on its fitness test statistics simultaneously and compared with the measurement model using Maximum Likelihood Estimation (MLE) with the statistical software package AMOS 26.0. As recommended by Hair, et al. [78], the goodness of fit of the hypothesized model was assessed and calculated using absolute indices and incremental indices [78].

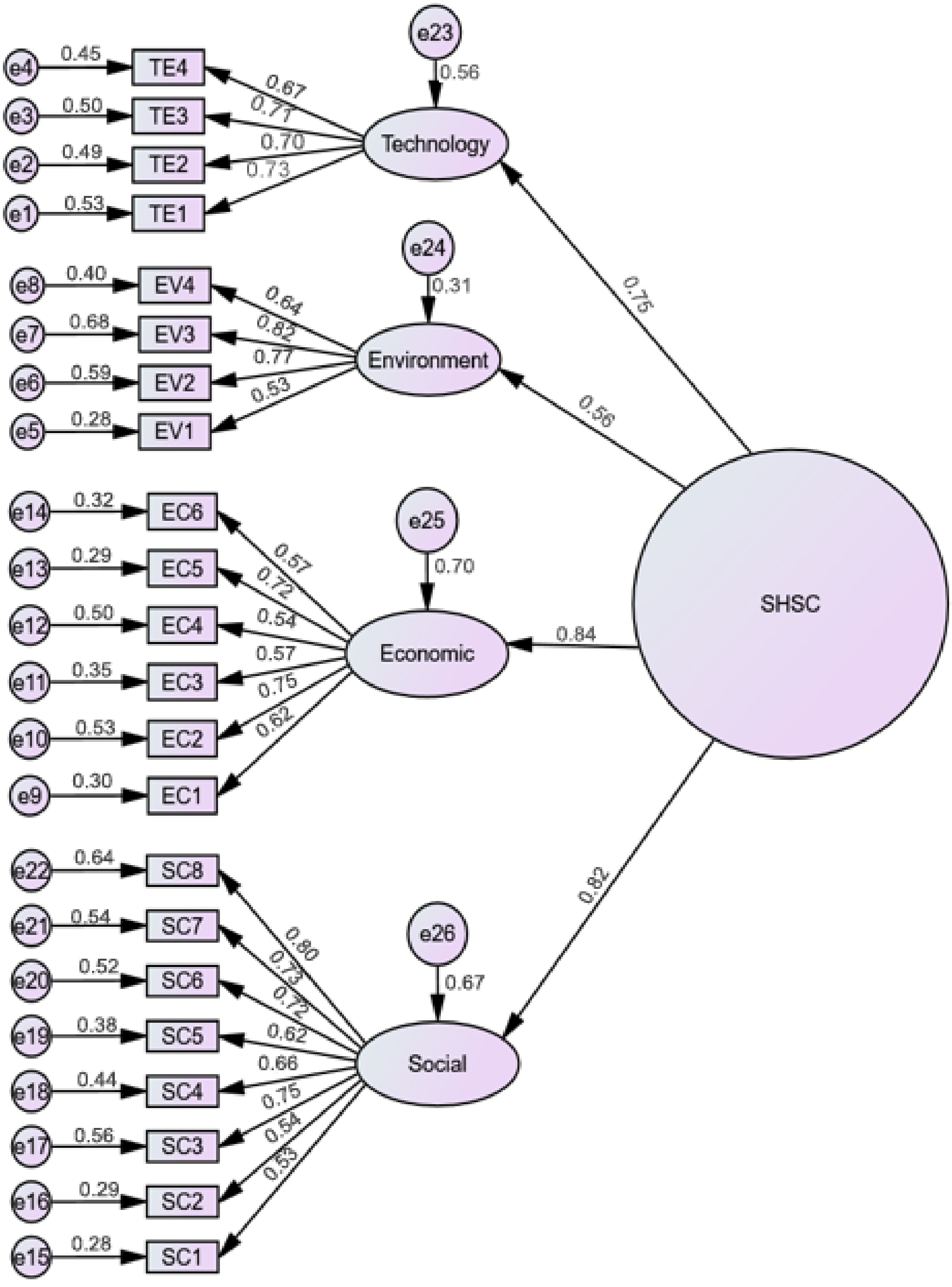

Figure 2.
SHSC second order structural equation model.

The results of the model absolute fit indices for the SHSC second-order structural equation model are shown in Table 6. The ratio of X^2/df (CMIN) was 1.167, which was far below the maximum acceptable value of 5. The goodness of fit (GFI), adjusted goodness of fit index (AGFI), and root-mean-square residual (RMR) values were 0.964, 0.932, and 0.015, respectively, which indicated that all absolute fit indices values met the requirements and that the model had good fit. Furthermore, the results of the model incremental fit indices, including the incremental fit index (IFI), normed fit index (NFI), Tucker–Lewis index (TLI), and comparative fit index (CFI), were 0.994, 0.961, 0.990, and 0.994, respectively. The statistical value also had a good level, meeting the recommended value to confirm the acceptance of the proposed model. Furthermore, the results of this comparative analysis are presented in the Table 6. The model fit tests indicate that the model with the second-order construct SHSC demonstrates superior fit compared to the alternative. This empirical evidence aligns with the theoretical underpinnings of this study, thereby providing robust support for this approach [79-81].

Table 6.
The goodness of fit of SEM.

Fit indices	Abbreviation	CFA value	SEM value	Recommended value	Reference
Absolute fit					
Chi-square	x^2	134.337	156.398		
Degree of freedom (Df)	df	120	134		
Chi-square significance (*p*-value)	*p*-value	0.000	0.000		
Chi-square/Degree of freedom	x^2/df	1.109	1.167	<5.0	Dillon, et al. [82]
Goodness-of-fit index	GFI	0.956	0.964	>0.9	Hu and Bentler [83]
Adjusted goodness-of-fit index	AGFI	0.924	0.932	>0.9	Hu and Bentler [83]
Root-mean-square residual	RMR	0.014	0.015	<0.05	Steiger [84]
Incremental fit					
Incremental fit index	IFI	0.912	0.994	>0.9	Hu and Bentler [83]
Normed fit index	NFI	0887	0.961	>0.9	Franke [85]
Tucker–Lewis index	TLI	0.899	0.990	>0.9	Crocetta, et al. [81]
Comparative fit index	CFI	0.911	0.994	>0.9	Franke [85]

The reliability, discriminant validity, correlation coefficients, and goodness of fit of SEM are presented in Tables 5 and 6. Hypothesis H1 can be confirmed the fact that H: the sustainable healthcare supply chain model that prioritize patient safety aligns with the empirical data.

The structural equation model, path analysis, and hypothesis test results were found using AMOS 26.0 after the overall analysis was done. They are shown in Table 5. Hypothesis H2 (β = 0.749, t = 10.372, p = ***) provided evidence that the social dimension is a significant component of the SHSC. Hypothesis H3 (β = 0.555, t = 9.890, p = ***) confirmed that the environmental dimension is a significant component of the SHSC. Hypothesis H4 (β = 0.747, t = 14.575, p = ***) confirmed that the economic dimension is a significant component of the SHSC. Finally, hypothesis H5 (β = 0.816, t = 14.387, p = ***) confirmed that the technology dimension is a significant component of the SHSC. Table 7 presents the results of hypothesis testing and shows that all the hypotheses were supported.

Table 7.
Hypothesis results for the structural model of SHSC.

Hypothesis	Path correlation	Standardized path coefficient *(β)*	S.E	C.R	*p*-value	Result
H2	SHSC --> Social	0.749	0.094	10.372	***	Supported
H3	SHSC --> Environmental	0.555	0.109	9.890	***	Supported
H4	SHSC --> Economic	0.747	0.098	14.575	***	Supported
H5	SHSC --> Technology	0.816	0.142	14.387	***	Supported

Note: S.E = Standard error, C.R = Critical ratio, *** p < 0.001.

In addition, the interrelations among each dimension were tested using AMOS 26.0. The results for the correlation, covariance, maximum shared value (MSV), and p-value are presented in Table 8. Hypotheses H6, H7, H8, H9, H10, and H11 were supported at p < 0.001.

Moreover, the MSV was less than the AVE from Table 5, which indicated that the model was valid and reliable. Therefore, the provided evidence confirmed that the social dimension correlates with the technology dimension. The environmental dimension correlates with the technology dimension. The economic dimension correlates with the technology dimension. The social dimension correlates with the economic dimension. The economic dimension correlates with the environmental dimension. Finally, the social dimension correlates with the environmental dimension.

Table 8.
Hypothesis results for correlate dimensions.

Hypothesis	Path correlation	Cor.	MSV	Cov.	S.E	C.R	*p*-value	Result
H6	Social <--> Technology	0.766	0.51	0.084	0.015	5.748	***	Supported
H7	Environmental <--> Technology	0.437	0.19	0.100	0.015	6.606	***	Supported
H8	Economic <--> Technology	0.540	0.29	0.150	0.019	8.037	***	Supported
H9	Social <--> Economic	0.711	0.51	0.048	0.008	6.058	***	Supported
H10	Economic <--> Environmental	0.615	0.38	0.034	0.006	5.314	***	Supported
H11	Social <--> Environmental	0.488	0.24	0.060	0.009	6.555	***	Supported

Note: Cor = Correlation, MSV = Maximum shared variance, Cov = Covariance, S.E = Standard error, C.R = Critical ratio, *** $p < 0.001$.

4.4. Application of the Model

The proposed and validated model was implemented in a healthcare facility in Phnom Penh, Cambodia. A tertiary hospital in Phnom Penh was selected for this study. Three hospital executives were selected for this study. The background of DMs is presented in Table 9. The steps of Fuzzy TOPSIS method were conducted as follows:

Table 9.
Linguistic scale for evaluating SHSC attributes of alternatives and criteria.

Experts	Job title	Gender	Education	Work experience
DM1	Hospital director	M	M.D	Over 20 years
DM2	Patient care unit director	M	M.D	Over 20 years
DM3	Procurement director	F	M.B.A	15–20 years

Step 1: The DMs rated the linguistic scale of criteria from the four dimensions of SHSC. An aggregate linguistic scale of the four dimensions was defined using TFN, as mentioned in Equation 1. The initial assessment score given by the DMs was then aggregated following Equation 2, and the results are shown in Table 10.

Table 10.
Linguistic assessment score and aggregated fuzzy weight of criteria by DMs.

Criteria	Linguistic assessment of criteria			Aggregate fuzzy weight of criteria		
	DM1	DM2	DM3			
Social	VI	VI	EI	5	7.67	9
Environment	EI	EI	EI	7	9	9
Economic	EI	EI	EI	7	9	9
Technology	EI	VI	VI	5	7.67	9

Additionally, the DMs evaluated the the 22 SHSC attributes using the linguistic scale while taking into account their level of importance. The linguistic assessment of the 22 attributes was presented as a fuzzy decision matrix to conduct the next step.

Step 2: The fuzzy decision matrix was normalized using a linear transformation as Equations (3)–(5). The fuzzy normalized matrix is presented in Table 11.

Table 11.
The fuzzy normalized matrix of the 22 attributes of SHSC.

Attributes	DM1	DM2	DM3
SC1	(0.56,0.78,1.00)	(0.78,1.00,1.00)	(0.78,1.00,1.00)
SC2	(0.78,1.00,1.00)	(0.78,1.00,1.00)	(0.78,1.00,1.00)
SC3	(0.78,1.00,1.00)	(0.33,0.56,0.78)	(0.56,0.78,1.00)
SC4	(0.56,0.78,1.00)	(0.33,0.56,0.78)	(0.56,0.78,1.00)
SC5	(0.78,1.00,1.00)	(0.56,0.78,1.00)	(0.78,1.00,1.00)
SC6	(0.33,0.56,0.78)	(0.56,0.78,1.00)	(0.56,0.78,1.00)
SC7	(0.56,0.78,1.00)	(0.33,0.56,0.78)	(0.33,0.56,0.78)
SC8	(0.78,1.00,1.00)	(0.56,0.78,1.00)	(0.78,1.00,1.00)
EV1	(0.56,0.78,1.00)	(0.78,1.00,1.00)	(0.78,1.00,1.00)
EV2	(0.33,0.56,0.78)	(0.78,1.00,1.00)	(0.33,0.56,0.78)
EV3	(0.56,0.78,1.00)	(0.33,0.56,0.78)	(0.78,1.00,1.00)
EV4	(0.56,0.78,1.00)	(0.78,1.00,1.00)	(0.56,0.78,1.00)
EC1	(0.56,0.78,1.00)	(0.33,0.56,0.78	(0.78,1.00,1.00)
EC2	(0.78,1.00,1.00)	(0.56,0.78,1.00)	(0.78,1.00,1.00)
EC3	(0.33,0.56,0.78)	(0.33,0.56,0.78)	(0.56,0.78,1.00)
EC4	(0.56,0.78,1.00)	(0.56,0.78,1.00)	(0.78,1.00,1.00)
EC5	(0.78,1.00,1.00)	(0.56,0.78,1.00)	(0.33,0.56,0.78)
EC6	(0.56,0.78,1.00)	(0.78,1.00,1.00)	(0.78,1.00,1.00)

Attributes	DM1	DM2	DM3
TE1	(0.78,1.00,1.00)	(0.56,0.78,1.00)	(0.56,0.78,1.00)
TE2	(0.56,0.78,1.00)	(0.78,1.00,1.00)	(0.78,1.00,1.00)
TE3	(0.78,1.00,1.00)	(0.78,1.00,1.00)	(0.78,1.00,1.00)
TE4	(0.56,0.78,1.00)	(0.78,1.00,1.00)	(0.33,0.56,0.78)

Step 3: The fuzzy weighted normalized matrix was then calculated using Equation 6. The results are presented in Table 12.

Table 12.
The fuzzy weighted normalized matrix of the 22 attributes of SHSC.

Attributes	DM1	DM2	DM3
SC1	(2.78,5.96,9.00)	(3.89,7.67,9.00)	(3.89,7.67,9.00)
SC2	(3.89,7.67,9.00)	(3.89,7.67,9.00)	(3.89,7.67,9.00)
SC3	(3.89,7.67,9.00)	(1.67,4.26,7.00)	(2.78,5.96,9.00)
SC4	(2.78,5.96,9.00)	(1.67,4.26,7.00)	(2.78,5.96,9.00)
SC5	(3.89,7.67,9.00)	(2.78,5.96,9.00)	(3.89,7.67,9.00)
SC6	(1.67,4.26,7.00)	(2.78,5.96,9.00)	(2.78,5.96,9.00)
SC7	(2.78,5.96,9.00)	(1.67,4.26,7.00)	(1.67,4.26,7.00)
SC8	(3.89,7.67,9.00)	(2.78,5.96,9.00)	(3.89,7.67,9.00)
EV1	(3.89,7.00,9.00)	(5.44,9.00,9.00)	(5.44,9.00,9.00)
EV2	(2.33,5.00,7.00)	(5.44,9.00,9.00)	(2.33,5.00,7.00)
EV3	(3.89,7.00,9.00)	(3.89,7.00,9.00)	(5.44,9.00,9.00)
EV4	(3.89,7.00,9.00)	(5.44,9.00,9.00)	(3.89,7.00,9.00)
EC1	(3.89,7.00,9.00)	(2.33,5.00,7.00)	(5.44,9.00,9.00)
EC2	(5.44,9.00,9.00)	(3.89,7.00,9.00)	(5.44,9.00,9.00)
EC3	(2.33,5.00,7.00)	(2.33,5.00,7.00)	(3.89,7.00,9.00)
EC4	(3.89,7.00,9.00)	(3.89,7.00,9.00)	(5.44,9.00,9.00)
EC5	(5.44,9.00,9.00)	(3.89,7.00,9.00)	(2.33,5.00,7.00)
EC6	(3.89,7.00,9.00)	(5.44,9.00,9.00)	(5.44,9.00,9.00)
TE1	(5.44,9.00,9.00)	(3.89,7.00,9.00)	(3.89,7.00,9.00)
TE2	(3.89,7.00,9.00)	(5.44,9.00,9.00)	(5.44,9.00,9.00)
TE3	(5.44,9.00,9.00)	(5.44,9.00,9.00)	(5.44,9.00,9.00)
TE4	(3.89,7.00,9.00)	(5.44,9.00,9.00)	(2.33,5.00,7.00)

Step 4: Equations 7and 8 were applied to calculate the FPIS (A^+), and FNIS (A^-). Subsequently, in step 5, the distance of each attribute from FPIS d_i^+ and FNIS d_i^- was calculated using Equations (9)–(11), respectively. Table 13 presents the distance of each attribute from the FPIS and FNIS.

Table 13.
Distance of each SHSC attribute from the FPIS and FNIS.

Attributes	FPIS			d_i^+	FNIS			d_i^-
SC1	1.17	0.00	0.00	1.17	1.65	2.62	2.62	6.88
SC2	0.00	0.00	0.00	0.00	2.62	2.62	2.62	7.85
SC3	0.00	2.62	1.17	3.79	2.62	0.00	1.65	4.26
SC4	1.17	2.62	1.17	4.97	1.65	0.00	1.65	3.29
SC5	0.00	1.17	0.00	1.17	2.62	1.65	2.62	6.88
SC6	2.62	1.17	1.17	4.97	0.00	1.65	1.65	3.29
SC7	1.17	2.62	2.62	6.41	1.65	0.00	0.00	1.65
SC8	0.00	1.17	0.00	1.17	2.62	1.65	2.62	6.88
EV1	1.46	0.00	0.00	1.46	1.86	1.46	3.15	6.47
EV2	3.15	0.00	3.15	6.29	0.00	1.46	0.00	1.46
EV3	1.46	1.46	0.00	2.93	1.86	0.00	3.15	5.01
EV4	1.46	0.00	1.46	2.93	1.86	1.46	1.86	5.19
EC1	1.46	3.15	0.00	1.46	1.86	0.00	3.15	5.01
EC2	0.00	1.46	0.00	0.00	3.15	1.86	3.15	8.15
EC3	3.15	3.15	1.46	3.15	0.00	0.00	1.86	1.86
EC4	1.46	1.46	0.00	1.46	1.86	1.86	3.15	6.87
EC5	0.00	1.46	3.15	0.00	3.15	1.86	0.00	5.01
EC6	1.46	0.00	0.00	1.46	1.86	3.15	3.15	8.15
TE1	0.00	1.46	0.00	1.46	1.46	0.00	1.86	3.33
TE2	1.46	0.00	1.46	2.93	0.00	1.46	3.15	4.61
TE3	0.00	0.00	1.46	1.46	1.46	1.46	3.15	6.07
TE4	1.46	0.00	1.86	3.33	0.00	1.46	0.00	1.46

Steps 6 and 7: the closeness coefficient CC_i of each SHSC attribute was computed using Equation 12. The 22 SHSC attributes that prioritized patient safety from the perspective of healthcare workers were ranked. The most important attribute was closest to the FPIS and farthest from the FNIS. The results are presented in Table 14.

Table 14.
Linguistic scale for evaluating SHSC attributes of alternatives and criteria.

Dimension	Attributes	d_i^+	d_i^-	CC_i	Rank
	SC1	1.17	6.88	0.854	2
	SC2	0.00	7.85	1.000	1
	SC3	3.79	4.26	0.529	5
	SC4	4.97	3.29	0.399	6
	SC5	1.17	6.88	0.854	2
	SC6	4.97	3.29	0.399	6
	SC7	6.41	1.65	0.204	8
	SC8	1.17	6.88	0.656	4
Social		2.96	5.12	0.634	(1)
	EV1	1.46	6.47	0.816	1
	EV2	6.29	1.46	0.189	4
	EV3	2.93	5.01	0.631	3
	EV4	2.93	5.19	0.640	2
Environment		3.40	4.53	0.571	(4)
	EC1	1.46	5.01	0.521	3
	EC2	0.00	8.15	0.848	1
	EC3	3.15	1.86	0.194	4
	EC4	1.46	6.87	0.701	2
	EC5	0.00	5.01	0.521	3
	EC6	1.46	8.15	0.848	1
Economic		3.80	5.84	0.606	(3)
	TE1	1.46	3.33	0.695	2
	TE2	2.93	4.61	0.612	3
	TE3	1.46	6.07	0.806	1
	TE4	3.33	1.46	0.305	4
Technology		2.29	3.87	0.628	(2)

According to the obtained results shown in Table 14, of CC_i the four dimensions, namely, social, environmental, economic, and technological, were 0.634, 0.571, 0.606, and 0.628, respectively. The results showed that the social dimension was the most important for SHSC from the perspective of healthcare workers in this organization. The technology dimension was ranked the second most important. The economic dimension was ranked the third most important, and the environmental dimension was ranked the least important. In the social dimension, the results showed that the most important attribute was SC2 (skills, knowledge and training). Within the technology dimension, the most important attribute was TE3 (transparency and traceability). In the economic dimension, the most important attribute was EC6 (leadership and governance). Finally, in the environmental dimension, the most important attribute was EV1 (waste management). Figure 3 illustrates the SHSC assessment and ranking by overall dimensions and by each attribute.

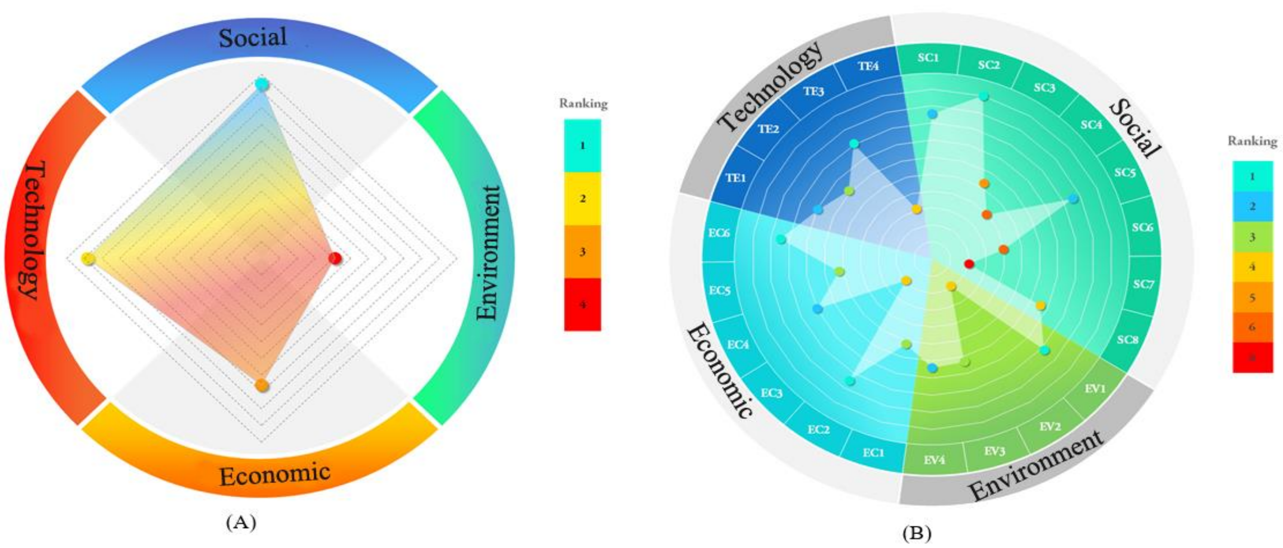

Figure 3.
The SHSC model for assessment and ranking (A) by overall dimension and (B) by each attribute.

4.5. Sensitivity Analysis

To ensure the robustness of the FTOPSIS results, a sensitivity analysis was performed. When conducting the sensitivity analysis in this study, it involved carrying out nine different scenarios by varying the criteria weights assigned to the four dimensions for all DMs. The scenarios included weights such as (0,1,3), (1,3,5), (3,5,7), (5,7,9), and (7,9,9) for the respective dimensions. The results of sensitivity analysis of the CC_i experiments are presented in Table 15 and Figure 4. The results demonstrated that the attributes exhibited robustness when subjected to changes in criteria weights. This finding confirmed the reliability of the importance assessment and ranking process, indicating that the attribute rankings remained consistent and reliable across different weight scenarios.

Table 15.
Sensitivity analysis experiments for nine different scenarios of the SHSC model.

Dimension	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9
Social	(0,1,3)	(1,3,5)	(3,5,7)	(5,7,9)	(7,9,9)	(7,9,9)	(0,1,3)	(0,1,3)	(0,1,3)
Environmental	(0,1,3)	(1,3,5)	(3,5,7)	(5,7,9)	(7,9,9)	(0,1,3)	(7,9,9)	(0,1,3)	(0,1,3)
Economic	(0,1,3)	(1,3,5)	(3,5,7)	(5,7,9)	(7,9,9)	(0,1,3)	(0,1,3)	(7,9,9)	(0,1,3)
Technology	(0,1,3)	(1,3,5)	(3,5,7)	(5,7,9)	(7,9,9)	(0,1,3)	(0,1,3)	(0,1,3)	(7,9,9)
Attributes	CC_i	CC_i	CC_i	CC_i	CC_i	CC_i	CC_i	CC_i	CC_i
SC1	0.357	0.275	0.163	0.543	0.779	0.347	0.324	0.431	0.586
SC2	0.357	0.268	0.213	0.606	0.757	0.348	0.324	0.471	0.671
SC3	0.362	0.298	0.192	0.509	0.641	0.353	0.308	0.339	0.396
SC4	0.363	0.303	0.155	0.448	0.645	0.352	0.308	0.303	0.321
SC5	0.357	0.275	0.163	0.589	0.779	0.347	0.324	0.431	0.586
SC6	0.363	0.303	0.155	0.378	0.645	0.352	0.308	0.303	0.321
SC7	0.367	0.318	0.211	0.365	0.430	0.357	0.294	0.254	0.222
SC8	0.357	0.275	0.163	0.589	0.779	0.347	0.324	0.431	0.586
EV1	0.388	0.338	0.205	0.359	0.716	0.343	0.324	0.342	0.533
EV2	0.394	0.360	0.294	0.140	0.189	0.330	0.255	0.220	0.170
EV3	0.388	0.342	0.230	0.388	0.631	0.347	0.340	0.353	0.468
EV4	0.388	0.342	0.237	0.269	0.640	0.344	0.296	0.294	0.414
EC1	0.355	0.299	0.174	0.327	0.521	0.281	0.296	0.323	0.395
EC2	0.350	0.280	0.169	0.473	0.848	0.291	0.383	0.436	0.607
EC3	0.359	0.316	0.238	0.209	0.194	0.273	0.226	0.225	0.203
EC4	0.351	0.286	0.121	0.394	0.701	0.291	0.336	0.379	0.506
EC5	0.355	0.299	0.174	0.327	0.521	0.281	0.296	0.323	0.395
EC6	0.350	0.280	0.169	0.473	0.848	0.291	0.383	0.436	0.607
TE1	0.336	0.410	0.350	0.311	0.695	0.386	0.356	0.377	0.436
TE2	0.336	0.408	0.330	0.424	0.612	0.389	0.405	0.430	0.502
TE3	0.336	0.406	0.314	0.389	0.806	0.383	0.399	0.443	0.592
TE4	0.3357	0.4058	0.3137	0.3891	0.8058	0.3831	0.3988	0.4426	0.5923

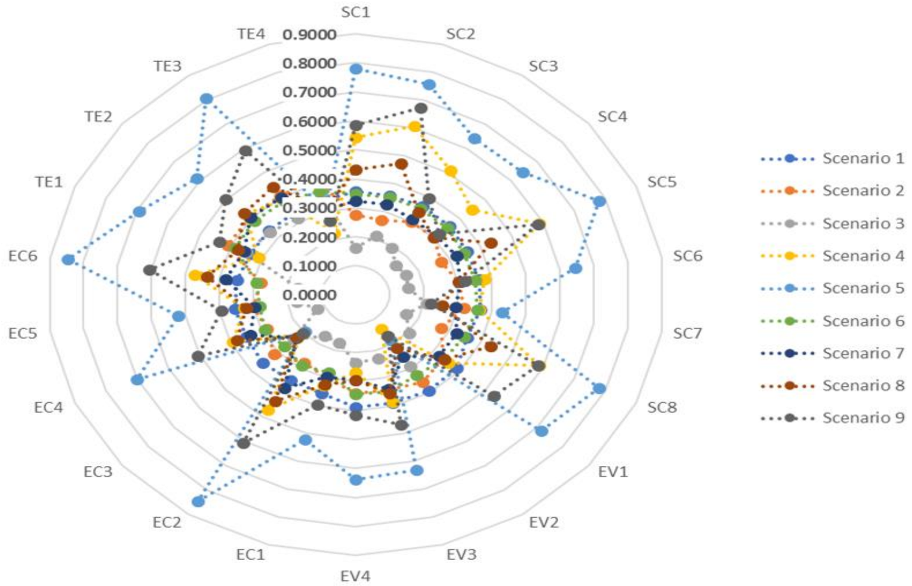

Figure 4.
Results of sensitivity analysis for SHSC attributes.

5. Discussion

In this study, the SHSC conceptual model, which prioritizes patient safety and incorporates healthcare workers′ perspectives, was adopted using the Fuzzy Delphi method [15]. The model encompassed 22 attributes grouped into four distinct dimensions: social, environmental, economic, and technological. A total of eleven hypotheses were formulated and subjected to rigorous testing. To ensure the reliability and internal consistency of the collected data, appropriate statistical measures were utilized. Exploratory Factor Analysis (EFA) was performed to validate the outcomes pertaining to the four dimensions and their corresponding attributes. Confirmatory Factor Analysis (CFA) was employed alongside a path diagram to effectively visualize the SHSC model. The second-order CFA and structural equation modelling approaches were employed to assess the significance and relative weight of each dimension and attribute within the SHSC model. Furthermore, all eleven hypotheses were subjected to robust statistical testing, resulting in their verification and acceptance, thereby providing empirical support for each hypothesis.

The empirical study presented the results of the first set of hypotheses, H2–H5. We found that the social, environmental, economic, and technological dimensions are all significant components of the SHSC. This aligned with the research by Khosravi and Izbirak [86], who emphasized the involvement of multiple stakeholders, including healthcare providers, manufacturers, distributors, and patients, in the healthcare supply chain [86]. Social factors play a vital role in influencing stakeholder engagement, collaboration, and communication throughout the supply chain. Cultural norms, social expectations, and community needs further influence how stakeholders interact and contribute to sustainable practices [86]. Additionally, Maghsoudi, et al. [87] emphasized the importance of stakeholder collaboration in improving social sustainability within healthcare and enhancing patient safety through sustainable approaches. This highlights the significance of collaborative efforts among stakeholders in promoting social sustainability and ensuring patient safety in a sustainable manner [87]. It was identified in H3 that the environmental dimension is a significant component of SHSC. Similar to the studies on the importance of the environment in the healthcare supply chain, we found that environmental considerations are essential due to the significant impact of healthcare operations on climate change. Healthcare facilities consume vast amounts of energy, produce greenhouse gas emissions, and generate medical waste. Sustainable healthcare supply chains focus on reducing their carbon footprint, conserving resources, and mitigating climate change through energy-efficient practices and waste reduction strategies [1, 34, 88]. Healthcare activities can generate various forms of pollution, including air and water pollution, hazardous waste, and chemical contamination. Sustainable healthcare supply chains prioritize pollution prevention measures, such as using environmentally friendly materials, implementing proper waste management systems, and adopting pollution control technologies [35, 36]. The findings of this study supported H4, indicating that the economic dimension is a significant component of the SHSC. Healthcare organizations that can effectively manage the supply of goods and services in a consistent and cost-effective manner, while prioritizing patient safety are able to achieve sustainability in the healthcare supply chain and gain a competitive edge over rivals [89, 90]. A noteworthy discovery in this research was the positive association of the technology dimension with SHSC, lending support to H5. Integrating the technology dimension into the traditional three pillars of the sustainable model represents a significant contribution. Technology has been increasingly playing a crucial role in the healthcare supply chain for several years [42]. However, the COVID-19 pandemic acted as a catalyst, making technology even more vital for supply chains, particularly within the healthcare sector, in order to enhance patient safety in a sustainable manner [58, 91-95].

The second set of hypotheses identified the correlations among the four dimensions. Hypothesis H6 identified that the social dimension has a correlation with the technology dimension. Technology can contribute to addressing social disparities in healthcare access. For example, telemedicine and mobile health technologies enable remote consultations, reaching patients in underserved areas. Electronic health records and data analytics help identify health inequities and target resources more effectively. Technology-driven initiatives promote social equity by ensuring equitable access to healthcare services and reducing barriers related to geography, mobility, and socio-economic status. Hypothesis H7 supports the notion that the environmental dimension correlates with the technology dimension. Healthcare organizations can leverage technology to integrate environmental considerations into their healthcare supply chains (HSC). This integration enables improvements in resource efficiency, waste reduction, environmental impact mitigation, and the promotion of sustainable practices. For instance, the application of green technology, such as energy-efficient equipment and the use of renewable energy sources, can help minimize energy consumption and reduce greenhouse gas emissions. Additionally, the design of healthcare facilities with smart management systems contributes to energy reduction [96]. Technology also plays a critical role in collaboration with suppliers by optimizing packaging and logistic practices, such as by incorporating recyclable and eco-friendly materials to minimize waste generation. Innovative technologies like blockchain and digital platforms facilitate traceability, accountability, and efficient inventory and waste management practices. H8 identified the correlation between the economic and technological dimensions. It is evident that economic and technological factors are closely intertwined. Various studies have emphasized the enabling effects of technology on cost efficiency, supply chain visibility, inventory management, supplier relationships, economic analysis, and innovation within the healthcare context [97]. By effectively leveraging technology, healthcare supply chains can achieve economic sustainability while simultaneously enhancing patient safety [98]. Hypothesis H9 identified that the social dimension has correlations with the economic dimension. By addressing social considerations, such as health equity, stakeholder engagement, and social determinants of health, healthcare supply chains can optimize economic performance, promote affordability, and contribute to overall societal well-being. Balancing both dimensions is crucial for achieving sustainable and equitable healthcare supply chains [99]. Hypothesis H10 provided support for the correlation between the economic dimension and the environmental dimension within healthcare supply chains. The integration of environmental sustainability practices in these supply chains can yield several benefits, including cost reductions, green procurement decisions, regulatory compliance, innovation, risk management, and enhanced brand reputation. By effectively balancing economic considerations with environmental objectives, healthcare supply chains can establish a sustainable and resilient operation that not only contributes to environmental preservation but also positively impacts their financial performance. This strategic alignment ensures that healthcare organizations can achieve long-term economic sustainability while simultaneously promoting environmental stewardship [90, 99-102]. Lastly, hypothesis H11 identified the correlations between the social dimension and environmental dimension, which contribute to driving sustainable healthcare supply chains for patient safety. By addressing social equity, patient well-being, environmental impact, employee safety, and emergency preparedness, healthcare supply chains can create a sustainable and safe environment that prioritizes patient safety and promotes overall health [90, 103]. An example that demonstrates the correlation between these two dimensions is environmental education for healthcare workers and patient engagement. Educating healthcare workers and patients about sustainable practices, such as proper medication disposal or energy conservation, empowers them to contribute to environmental protection while ensuring their safety. Engaging patients in sustainability initiatives fosters a sense of social responsibility and environmental stewardship, positively impacting patient safety and environmental conservation [15].

After conducting SEM and hypothesis testing, Fuzzy TOPSIS was employed to rank the attributes of SHSC within each dimension. The proposed SHSC model was implemented in a case study conducted at a tertiary hospital in Phnom Penh, Cambodia. The participants in the study were hospital executives, selected as a group of decision-makers (DMs). The results of Fuzzy TOPSIS showed that the social dimension was the most crucial, then the economic, environmental, and technological dimensions. Upon closer examination of each dimension, the attribute that healthcare experts prioritized the most in the social dimension was "SC2: Skills, Knowledge, and Training." In the technology dimension, the attribute deemed most important was "TE3: Transparency and Traceability." Within the economic dimension, the most significant attributes were "EC2: Process Efficiency" and "EC6: Leadership and Governance." Finally, in the environmental dimension, the attribute that held the highest importance was "EV1: Waste Management."

Based on the aforementioned ranked findings, the identification of the most important attribute in each dimension offers valuable insights for hospital executives. This information enables them to prioritize specific areas and devise strategies aimed at enhancing SHSC practices. Such efforts not only contribute to improving patient safety but also enhance competitiveness and cost-effectiveness within the healthcare sector. The managerial implications of this study can be summarized as follows:

5.1. Skills, Knowledge, and Training

Enhancing skills for healthcare workers is vital for sustainable healthcare. It leads to quality patient care, adaptability to change, efficient operations, patient safety, collaboration, addressing health disparities, and fostering innovation. By investing in the professional development of healthcare workers, we can build a sustainable healthcare workforce that can effectively meet the evolving needs of patients and contribute to the long-term success of healthcare systems. Continuous skill development and training will enable healthcare workers to provide high-quality patient care. Staying updated with the latest medical advancements, treatment protocols, and best practices ensures that healthcare professionals can deliver effective and evidence-based care, resulting in improved patient outcomes and safety.

5.2. Transparency and Traceability

Blockchain technology is an example of a technology that can benefit from the reasons mentioned in the context of transparency and traceability in sustainable healthcare. Blockchain is a decentralized and transparent digital ledger that allows secure and immutable recording of transactions. Adopting technology like block-chains enables end-to-end traceability of healthcare products, from manufacturing to delivery. Each transaction or movement of a product can be recorded on the blockchain, creating an auditable and transparent supply chain. This helps identify the origin of products, track their handling, and verify their authenticity, ensuring patient safety and combating counterfeit products. While blockchain technology offers several potential benefits, it is important to consider its implementation challenges, such as scalability, interoperability, and data privacy. Addition-ally, other technologies, such as Internet of Things (IoT), Artificial Intelligence (AI), and data analytics, can also contribute to transparency and traceability in sustainable healthcare by collecting and analyzing real-time data, improving decision-making, and optimizing processes. The choice of technology depends on specific organizational needs and the context in which it is applied.

5.3. Process Efficiency

To improve process efficiency, healthcare organizations can employ various strategies. One effective approach is the application of lean principles, which include just-in-time inventory management, waste reduction initiatives, and continuous improvement practices. By eliminating waste, optimizing resource utilization, and fostering a culture of continuous improvement, healthcare organizations can enhance patient safety while simultaneously reducing costs and environmental impact. Implementing process standardization plays a pivotal role in reducing variability, eliminating inefficiencies, and enhancing overall efficiency. Clear guidelines, protocols, and best practices ensure consistency in tasks such as inventory management, product handling, and transportation. This reduces errors, streamlines operations, and improves patient safety. Furthermore, effective communication and collaboration among stakeholders in the healthcare supply chain are vital for achieving process efficiency and enhancing patient safety. Implementing robust communication channels, sharing real-time information, and fostering collaboration between healthcare providers, suppliers, and logistics partners enables better coordination, faster response times, and improved overall efficiency.

5.4. Leadership and Governance

Effective leadership plays a critical role in driving sustainable healthcare supply chains. It begins with establishing a clear vision and goals that emphasize patient safety, sustainability, and ethical practices across the supply chain. Leaders should communicate this vision to stakeholders, fostering a shared understanding and commitment to excellence and accountability. Cultivating a strong culture of safety is paramount. Leaders must prioritize patient safety as a core value and actively promote it among all stakeholders. This involves fostering open communication channels, encouraging the reporting of safety incidents and near-misses, and ensuring that safety concerns are promptly addressed. By nurturing a culture of safety, employees are empowered to take ownership of patient safety and actively contribute to continuous improvement efforts. Additionally, leaders should engage stakeholders in decision-making processes, promoting transparency and fostering strong relationships. This ensures that patient safety and sustainability considerations are integrated throughout the supply chain, fostering a collaborative and responsible approach.

5.5. Waste Management

- Implementing effective waste management strategies is crucial for sustainable healthcare supply chains. Some examples of strategies to achieve efficient waste management for SHSC include implementing a comprehensive waste segregation and classification system within the healthcare supply chain and properly categorizing waste streams into different types, such as general waste, hazardous waste, pharmaceutical waste, and recyclable materials. This ensures appropriate handling, storage, and disposal of different waste types, reducing the risk of cross-contamination and environmental harm.
- Implement waste reduction strategies to minimize waste generation at the source. This includes adopting practices such as inventory management optimization to prevent overstocking and expiration of medical supplies, implementing lean principles to reduce process waste, and encouraging the use of digital documentation instead of paper-based systems. By reducing waste generation, healthcare organizations can minimize environmental impacts and optimize resource utilization.
- Implement recycling programs within the healthcare supply chain to maximize resource recovery. Identify recyclable materials, such as plastics, paper, and packaging, and establish systems to collect, segregate, and recycle them appropriately. Partner with recycling vendors or organizations to ensure proper disposal and recycling of recyclable waste, reducing landfill waste, and conserving resources.
- Develop and implement safe disposal protocols for hazardous waste generated within the healthcare supply chain, such as chemicals, sharps, and pharmaceutical waste.
- Provide comprehensive training and education programs to healthcare personnel regarding waste management practices. Educate staff on proper waste segregation, handling, and disposal procedures. Promote awareness of the environmental and patient safety impacts of improper waste management practices. Empower employees to take responsibility for waste management and actively participate in waste reduction efforts
- Collaborate with suppliers and partners within the healthcare supply chain to implement sustainable waste management practices. Encourage suppliers to adopt environmentally friendly packaging and reduce unnecessary packaging materials. Foster partnerships with waste management service providers who prioritize sustainability and adhere to responsible waste disposal practices. By implementing these strategies, healthcare organizations can effectively manage waste in the supply chain, promote patient safety, reduce environmental impact, and contribute to sustainable healthcare practices.

6. Conclusion

Establishing a sustainable healthcare supply chain (SHSC) requires careful consideration of its various components and stakeholders. Prioritizing attributes within the SHSC framework is essential for effective strategizing. The healthcare sector plays a critical role in promoting social, environmental, and economic sustainability, and technology integration is key to driving SHSC for patient safety. The successful implementation of prioritized strategies is crucial for SHSC effectiveness. This study provides significant contributions as follows: Firstly, the SHSC model has been validated, uniquely blending technology with the traditional three sustainability pillars, thereby augmenting the framework's depth and relevance. Secondly, this study gives healthcare organizations a critical assessment tool that they can use to look closely at their own contextual factors, identify key factors, and then make effective SHSC strategies. This study emphasizes that patient safety is the most important goal in healthcare services.

6.1. Limitations and Future Research

While the novel SHSC model proposed in this research study offers valuable in-sights for healthcare executives and leaders in their pursuit of holistic sustainability, it is important to acknowledge certain limitations, which include the following:

- The survey, tailored to Cambodian healthcare workers, may limit the model's generalizability to other sectors or countries. Future research should validate this model in varied contexts, explore its relevance across regions, and compare it with other MCDM methods to enrich the SHSC model's understanding and applicability.
- This study builds upon Kanokphanvanich, et al. [15], which pinpointed key SHSC attributes from the vantage of HSC experts in Southeast Asia's developing nations. It's crucial to note, however, that our regional focus and

literature review approach might have missed some pivotal attributes tied to patient safety in SHSC. Expanding the pool of decision-makers in future research could enhance accuracy and provide richer insights.

- This study primarily focuses on the current state of supply chains in the healthcare industry in Cambodia, and the proposed hybrid model is validated under specific conditions. The dynamic and evolving nature of healthcare supply chains, influenced by technological advancements, regulatory changes, and global events, means that adaptability becomes a crucial aspect. The present study doesn't deeply explore the model's adaptability under diverse, unpredictable scenarios or shifting conditions. Future research should rigorously evaluate the model's resilience and flexibility in such dynamic contexts to ensure its robust applicability across a broader spectrum of situations.
- In this study, we introduce an innovative supply chain model that integrates technology into a traditional sustainable framework. Given the distinctive nature of our research, it lacks comparable findings from similar studies, thereby highlighting a promising path for future research endeavors.
- While the hybrid SEM-Fuzzy TOPSIS method offers significant advantages, it's essential to acknowledge its limitations, which can pave the way for future research opportunities. Structural Equation Modeling (SEM) offers powerful insights into relationships among variables, but it does come with constraints. The method assumes data normality and linearity, and its results can be sensitive to both sample size and potential measurement errors. Moreover, despite its ability to suggest causal relationships, it can't conclusively determine causality, especially in the presence of omitted variables or cross-sectional data. Additionally, model mis-specification and software-specific quirks can further complicate interpretations. The assignment of weights to criteria in Fuzzy TOPSIS is often subjective, based on expert judgment or decision-maker preferences. This subjectivity can introduce potential biases in this study. Therefore, for a more comprehensive understanding, future research should explore and compare other methods to SEM-TOPSIS, enriching the insights and potentially addressing some of the limitations mentioned.
- One of the promising directions for future research would be to assess the robustness and adaptability of the hybrid model in the face of changing conditions and uncertainties. This could involve stress-testing the model under various scenarios, both anticipated and unanticipated, to understand its limitations and potential modifications required. Incorporating real-time data, predictive analytics, and scenario planning might be potential avenues to enhance the model's flexibility and responsiveness. This would not only improve the model's practicality but also its longevity in the rapidly evolving healthcare supply chain landscape

References

[1] B. R. Keeble, "The Brundtland report:'Our common future'," *Medicine and war*, vol. 4, no. 1, pp. 17-25, 1988.

[2] R. B. Johnston, "Transforming our world: The 2030 agenda for sustainable development," in *In Proceedings of the 6th International Congress on Arsenic in the Environment, AS 2016, Stockholm, Sweden*, 2016, pp. 19–23.

[3] World Health Organization (WHO), *WHO timeline—COVID-19; Wold health organization*. Geneva, Switzerland: WHO, 2020.

[4] A. R. Jazieh and Z. Kozlakidis, "Healthcare transformation in the post-coronavirus pandemic era," *Frontiers in Medicine*, vol. 7, p. 429, 2020. https://doi.org/10.3389/fmed.2020.00429

[5] H. Balfour, "COVID-19 Update: Coronavirus and the pharmaceutical supply chain, European Pharmaceutical Review," Retrieved: https://www.europeanpharmaceuticalreview.com/article/116145/covid-19-update-coronavirus-and-the-pharmaceutical-supply-chain/ [Accessed 2020.

[6] A. Erjaee, S. Hendiani, S. Moradi, and M. Bagherpour, "Healthcare sustainability evaluation using a hybrid fuzzy multi-criteria decision-making model," *International Journal of Fuzzy Systems*, pp. 1-21, 2022. https://doi.org/10.1007/s40815-021-01128-4

[7] J. Grundy, Q. Y. Khut, S. Oum, P. Annear, and V. Ky, "Health system strengthening in Cambodia—a case study of health policy response to social transition," *Health Policy*, vol. 92, no. 2-3, pp. 107-115, 2009.

[8] Kingdom of Cambodia, "Kingdom of Cambodia nation religion King Kingdom of Cambodia nation religion King Quality, effective and equitable health services," Retrieved: http://hismohcambodia.org/public/fileupload/carousel/HSP3-(2016-2020). [Accessed 1 May 2022], 2016.

[9] Large-Scale Malaria, "Large-scale malaria treatment in the private Sector: A case study of the Cambodian experience," Retrieved: https://globalhealthsciences.ucsf.edu/sites/globalhealthsciences.ucsf.edu/files/pub/hsi-cambodia-case-study.pdf. [Accessed 1 May 2022], 2022.

[10] CSDG Framework-2016-2030, "CSDG Framework-2016-2030 English," Retrieved: https://ncsd.moe.gov.kh/sites/default/files/2019-06/CSDG_Framework_2016-2030_English_LAST_FINAL.pdf. [Accessed 15 March 2022], 2018.

[11] Cambodia, "Cambodia: Development news, research, data |World Bank|," Retrieved: https://www.worldbank.org/en/country/cambodia. [Accessed 2 June 2023], 2023.

[12] A. Iwamoto, R. Tung, T. Ota, S. Hosokawa, and M. Matsui, "Challenges to neonatal care in Cambodia amid the COVID-19 pandemic," *Global Health & Medicine*, vol. 2, no. 2, pp. 142-144, 2020. https://doi.org/10.35772/ghm.2020.01030

[13] B. Nit *et al.*, "Understanding the slow COVID-19 trajectory of Cambodia," *Public Health in Practice*, vol. 2, p. 100073, 2021. https://doi.org/10.1016/j.puhip.2020.100073

[14] P. L. Annear *et al.*, "The Kingdom of cambodia health system review," *Health Systems in Transition*, vol. 5, pp. 20–41, 2015.

[15] C. Kanokphanvanich, W. Rattanawong, and V. Vongmanee, "A new model for a sustainable healthcare supply chain prioritizes patient safety: Using the fuzzy delphi method to identify healthcare workers' perspectives," *Sustainability*, vol. 15, no. 9, p. 7123, 2023. https://doi.org/10.3390/su15097123.

[16] M. K. Hossain and V. Thakur, "Drivers of sustainable healthcare supply chain performance: Multi-criteria decision-making approach under grey environment," *International Journal of Quality & Reliability Management*, vol. 39, no. 3, pp. 859-880, 2022. https://doi.org/10.1108/IJQRM-03-2021-0075

[17] N. K. Arora and I. Mishra, "United nations sustainable development Goals 2030 and environmental sustainability: Race against time," *Environmental Sustainability,* vol. 2, no. 4, pp. 339-342, 2019. https://doi.org/10.1007/s42398-019-00092-y

[18] WHO, *Draft global patient safety action plan 2021–2030; In Towards Eliminating Avoidable Harm in Health Care; Angewandte Chemie International Edition*. Geneva, Switzerland: WHO, 2021.

[19] T. Supeekit, T. Somboonwiwat, and D. Kritchanchai, "Causal relationship of supply chain efficiency and patient safety in measuring internal hospital supply chain performance applying DEMATEL," in *In Proceedings of the CIE 2014—44th International Conference on Computers and Industrial Engineering and IMSS 2014—9th International Symposium on Intelligent Manufacturing and Service Systems, Joint International Symposium on "The Social Impacts of Developments in Information, Istanbul, Turkey*, 2014, pp. 988–1001.

[20] M. M. Vali-Siar and E. Roghanian, "Sustainable, resilient and responsive mixed supply chain network design under hybrid uncertainty with considering COVID-19 pandemic disruption," *Sustainable Production and Consumption,* vol. 30, pp. 278-300, 2022. https://doi.org/10.1016/j.spc.2021.12.003

[21] T. Ben-Zvi and J. Luftman, "Post-pandemic IT: Digital transformation and sustainability," *Sustainability,* vol. 14, no. 22, p. 15275, 2022. https://doi.org/10.3390/su142215275

[22] M. Chandra, K. Kumar, P. Thakur, S. Chattopadhyaya, F. Alam, and S. Kumar, "Digital technologies, healthcare and COVID-19: Insights from developing and emerging nations," *Health and Technology,* vol. 12, no. 2, pp. 547-568, 2022.

[23] M. Alhasan and M. Hasaneen, "Digital imaging, technologies and artificial intelligence applications during COVID-19 pandemic," *Computerized Medical Imaging and Graphics,* vol. 91, p. 101933, 2021. https://doi.org/10.1016/j.compmedimag.2021.101933

[24] L. Franchina, A. Calabrese, G. Inzerilli, E. Scatto, G. Brutti, and M. V. de los Ángeles Bonanni, "Thinking green: The role of smart technologies in transforming cities' waste and supply Chain's flow," *Cleaner Engineering and Technology,* vol. 2, p. 100077, 2021. https://doi.org/10.1016/j.clet.2021.100077.

[25] Y. A. Singh, G. Pandey, T. K. Arora, and P. K. Chaubey, "Block-chain application based economic impact of coronavirus pandemic on medicine industry inventory system for deteriorating objects with two-warehouse and wastewater treatment using PSO," *Materials Today: Proceedings,* vol. 51, pp. 939-946, 2022. https://doi.org/10.1016/j.matpr.2021.06.307

[26] C. Kanokphanvanich, W. Rattanawong, and V. Vongmanee, "A meta-analysis of health care supply chain performance for patient safety," in *Proceedings of the International Conference on Software, Knowledge Information, Industrial Management and Applications, SKIMA; Institute of Electrical and Electronics Engineers Inc.: ; Vol. 2022-December*, 2022, pp. 13–20.

[27] A. F. Huq, M. Stevenson, and M. Zorzini, "Social sustainability in developing country suppliers: An exploratory study in the ready made garments industry of Bangladesh," *International Journal of Operations & Production Management,* vol. 34, no. 5, pp. 610-638, 2014. https://doi.org/10.1108/IJOPM-10-2012-0467

[28] V. Mani, R. Agrawal, and V. Sharma, "Social sustainability in the supply chain: Analysis of enablers," *Management Research Review,* vol. 38, no. 9, pp. 1016-1042, 2015. https://doi.org/10.1108/MRR-02-2014-0037.

[29] M. Hussain, M. M. Ajmal, A. Gunasekaran, and M. Khan, "Exploration of social sustainability in healthcare supply chain," *Journal of Cleaner Production,* vol. 203, pp. 977-989, 2018. https://doi.org/10.1016/j.jclepro.2018.08.157.

[30] M. R. Sarker, M. A. Moktadir, and E. D. Santibanez-Gonzalez, "Social sustainability challenges towards flexible supply chain management: Post-COVID-19 perspective," *Global Journal of Flexible Systems Management,* vol. 22, pp. 199-218, 2021. https://doi.org/10.1007/s40171-021-00289-3

[31] K. Govindan, M. Shaw, and A. Majumdar, "Social sustainability tensions in multi-tier supply chain: A systematic literature review towards conceptual framework development," *Journal of Cleaner Production,* vol. 279, p. 123075, 2021. https://doi.org/10.1016/j.jclepro.2020.123075

[32] S. Cheang and J.-D. Lee, "Evaluation telecenter performance in social sustainability context: A cambodia case study," in *Proceedings of the 6th International Conference on Advanced Information Management and Service (IMS), Seoul, Republic of Korea, 30 November–2 December 2010*, 2010.

[33] X. Yang and K. Lo, "Environmental health research and the COVID-19 pandemic: A turning point towards sustainability," *Environmental Research,* vol. 197, p. 111157, 2021. https://doi.org/10.1016/j.envres.2021.111157

[34] C. Kumar and R. Chaudhary, "Environmental sustainability practices in hospitals of Bihar," *Current Research in Environmental Sustainability,* vol. 3, p. 100106, 2021. https://doi.org/10.1016/j.crsust.2021.100106

[35] S. A. Woolen *et al.*, "Radiology environmental impact: What is known and how can we improve?," *Academic Radiology,* vol. 30, no. 4, pp. 625-630, 2023. https://doi.org/10.1016/j.acra.2022.10.021

[36] S. Khalid, C. Beattie, J. Sands, and V. Hampson, "Incorporating the environmental dimension into the balanced scorecard: A case study in health care," *Meditari Accountancy Research,* vol. 27, no. 4, pp. 652-674, 2019. https://doi.org/10.1108/MEDAR-06-2018-0360

[37] A. Tajbakhsh and E. Hassini, "Performance measurement of sustainable supply chains: A review and research questions," *International Journal of Productivity and Performance Management,* vol. 64, no. 6, pp. 744-783, 2015. https://doi.org/10.1108/IJPPM-03-2013-0056

[38] S. J. Williams and Z. J. Radnor, "Moving from service to sustainable services: A healthcare case study," *International Journal of Productivity and Performance Management,* vol. 71, no. 4, pp. 1126-1148, 2022. https://doi.org/10.1108/IJPPM-12-2019-0583

[39] P. Senna, A. Reis, I. L. Santos, A. C. Dias, and O. Coelho, "A systematic literature review on supply chain risk management: Is healthcare management a forsaken research field?," *Benchmarking: An International Journal,* vol. 28, no. 3, pp. 926-956, 2020. https://doi.org/10.1108/BIJ-05-2020-0266

[40] V. Swarnakar, A. Singh, and A. K. Tiwari, "Evaluating the effect of critical failure factors associated with sustainable Lean Six Sigma framework implementation in healthcare organization," *International Journal of Quality & Reliability Management,* vol. 38, no. 5, pp. 1149-1177, 2021. https://doi.org/10.1108/IJQRM-07-2020-0243

[41] R. Rodriguez, C. Otero-Neira, and G. Svensson, "Sustainability endeavors and sustainable development in Spanish public hospitals: The case for upstream social marketing," *Journal of Social Marketing,* vol. 10, no. 2, pp. 215-242, 2020. https://doi.org/10.1108/JSOCM-11-2018-0136

[42] What Is the Role of Technology, "What is the role of technology in strengthening the healthcare supply chain?," Retrieved: https://appinventiv.com/blog/technology-strengthening-healthcare-supply-chain/. [Accessed 22 January 2023], 2023.

[43] D. Chandra and D. Kumar, "Evaluating the effect of key performance indicators of vaccine supply chain on sustainable development of mission indradhanush: A structural equation modeling approach," *Omega,* vol. 101, p. 102258, 2021. https://doi.org/10.1016/j.omega.2020.102258

[44] C. Bialas, D. Bechtsis, E. Aivazidou, C. Achillas, and D. Aidonis, "A holistic view on the adoption and cost-effectiveness of technology-driven supply chain management practices in healthcare," *Sustainability,* vol. 15, no. 6, p. 5541, 2023. https://doi.org/10.3390/su15065541

[45] S. Kumar, R. D. Raut, and B. E. Narkhede, "A proposed collaborative framework by using artificial intelligence-internet of things (AI-IoT) in COVID-19 pandemic situation for healthcare workers," *International Journal of Healthcare Management,* vol. 13, no. 4, pp. 337-345, 2020. https://doi.org/10.1080/20479700.2020.1810453

[46] G. Singleton *et al.*, "UK healthcare workers' experiences of major system change in elective surgery during the COVID-19 pandemic: Reflections on rapid service adaptation," *International Journal of Health Policy and Management,* vol. 11, no. 10, p. 2072, 2022. https://doi.org/10.34172/ijhpm.2021.101

[47] C. C. Liu *et al.*, "RFID-initiated workflow control to facilitate patient safety and utilization efficiency in operation theater," *Computer Methods and Programs in Biomedicine,* vol. 104, no. 3, pp. 435-442, 2011. https://doi.org/10.1016/j.cmpb.2010.08.017

[48] M. Haddara and A. Staaby, "RFID applications and adoptions in healthcare: A review on patient safety," *Procedia Computer Science,* vol. 138, pp. 80-88, 2018. https://doi.org/10.1016/j.procs.2018.10.012

[49] G. Borelli, P. F. Orrù, and F. Zedda, "Performance analysis of a healthcare supply chain, A RFID system implementation design," in *Proceedings of the Summer School Francesco Turco*, 2013, vol. 11, pp. 42-47.

[50] A. I. Paganelli *et al.*, "A conceptual IoT-based early-warning architecture for remote monitoring of COVID-19 patients in wards and at home," *Internet of Things,* vol. 18, p. 100399, 2022. https://doi.org/10.1016/j.iot.2021.100399

[51] M. C. K. Lee, C. M. Na, and N. C. Kit, "IoT-based asset management system for healthcare-related industries," *International Journal of Engineering Business Management,* vol. 7, p. 19, 2015.

[52] V. Duque-Uribe, W. Sarache, and E. V. Gutiérrez, "Sustainable supply chain management practices and sustainable performance in hospitals: A systematic review and integrative framework," *Sustainability,* vol. 11, no. 21, p. 5949, 2019. https://doi.org/10.3390/su11215949

[53] M. Ranjbari *et al.*, "Three pillars of sustainability in the wake of COVID-19: A systematic review and future research agenda for sustainable development," *Journal of Cleaner Production,* vol. 297, p. 126660, 2021. https://doi.org/10.1016/j.jclepro.2021.126660

[54] R. Banerjee, K. Gupta, and P. Mudalige, "Do environmentally sustainable practices lead to financially less constrained firms? International evidence," *International Review of Financial Analysis,* vol. 68, p. 101337, 2020. https://doi.org/10.1016/j.irfa.2019.03.009

[55] N. Mukati, N. Namdev, R. Dilip, N. Hemalatha, V. Dhiman, and B. Sahu, "Healthcare assistance to COVID-19 patient using internet of things (IoT) enabled technologies," *Materials Today: Proceedings,* vol. 80, pp. 3777-3781, 2023. https://doi.org/10.1016/j.matpr.2021.07.379

[56] H. J. A. Dalal, V. Ramoo, M. C. Chong, M. Danaee, Y. I. Aljeesh, and V. U. Rajeswaran, "The mediating role of work satisfaction in the relationship between organizational communication satisfaction and organizational commitment of healthcare professionals: A cross-sectional study," *Healthcare,* vol. 11, p. 806, 2023. https://doi.org/10.3390/healthcare11060806

[57] J.-Y. Ma, L. Shi, and T.-W. Kang, "The effect of digital transformation on the pharmaceutical sustainable supply chain performance: The mediating role of information sharing and traceability using structural equation modeling," *Sustainability,* vol. 15, no. 1, p. 649, 2023. https://doi.org/10.3390/su15010649

[58] Y. O. Akinwale and H. M. AboAlsamh, "Technology innovation and healthcare performance among healthcare organizations in Saudi Arabia: A structural equation model analysis," *Sustainability,* vol. 15, no. 5, p. 3962, 2023. https://doi.org/10.3390/su15053962

[59] H. K. Kim and C. W. Lee, "Relationships among healthcare digitalization, social capital, and supply chain performance in the healthcare manufacturing industry," *International Journal of Environmental Research and Public Health,* vol. 18, no. 4, p. 1417, 2021. https://doi.org/10.3390/ijerph18041417

[60] S. Mukherjee, M. M. Baral, V. Chittipaka, S. K. Pal, and R. Nagariya, "Investigating sustainable development for the COVID-19 vaccine supply chain: A structural equation modelling approach," *Journal of Humanitarian Logistics and Supply Chain Management,* vol. 13, no. 2, pp. 199-215, 2022. https://doi.org/10.1108/jhlscm-08-2021-0079

[61] W. Suksatan, S. Teravecharoenchai, and J. Sarayuthpitak, "Health-promoting behaviors among older adults with noncommunicable diseases in rural and urban areas during the new Normal post-COVID-19 era: A structural equation modeling analysis," *Nutrients,* vol. 15, no. 1, p. 101, 2022. https://doi.org/10.3390/nu15010101

[62] A. Attaallah *et al.*, "Fuzzy-based unified decision-making technique to evaluate security risks: A healthcare perspective," *Mathematics,* vol. 11, no. 11, p. 2554, 2023. https://doi.org/10.3390/math11112554

[63] H. M. Alshahrani *et al.*, "Analysis and ranking of IT risk factors using fuzzy TOPSIS-based approach," *Applied Sciences,* vol. 12, no. 12, p. 5911, 2022. https://doi:10.3390/app12125911

[64] L. E. Van Zyl and P. M. Ten Klooster, "Exploratory structural equation modeling: Practical guidelines and tutorial with a convenient online tool for Mplus," *Frontiers in Psychiatry,* vol. 12, p. 795672, 2022. https://doi.org/10.3389/fpsyt.2021.795672

[65] H. Sun, B. Zhang, and W. Ni, "A hybrid model based on SEM and fuzzy TOPSIS for supplier selection," *Mathematics,* vol. 10, no. 19, p. 3505, 2022. https://doi.org/10.3390/math10193505

[66] Y. Luo, X. Jie, X. Li, and L. Yao, "Ranking Chinese SMEs green manufacturing drivers using a novel hybrid multi-criterion decision-making model," *Sustainability,* vol. 10, no. 8, p. 2661, 2018. https://doi.org/10.3390/su10082661

[67] M. S. Kirkire, S. B. Rane, and G. J. Abhyankar, "Structural equation modelling–FTOPSIS approach for modelling barriers to product development in medical device manufacturing industries," *Journal of Modelling in Management,* vol. 15, no. 3, pp. 967-993, 2020. https://doi.org/10.1108/jm2-09-2018-0139

[68] C. Bialas, D. Bechtsis, E. Aivazidou, C. Achillas, and D. Aidonis, "Digitalization of the healthcare supply chain through the adoption of enterprise resource planning (ERP) systems in hospitals: An empirical study on influencing factors and cost performance," *Sustainability*, vol. 15, no. 4, p. 3163, 2023. https://doi.org/10.3390/su15043163

[69] M. F. Nazir and S. F. Qureshi, "Applying structural equation modelling to understand the implementation of social distancing in the professional lives of healthcare workers," *International Journal of Environmental Research and Public Health*, vol. 20, no. 5, p. 4630, 2023. https://doi.org/10.3390/ijerph20054630

[70] S. J. Chen, C. Hwang, M. J. Beckmann, and W. Krelle, "Multiple attribute decision making: Methods and applications," Retrieved: http://ci.nii.ac.jp/ncid/BA13989475. 1981.

[71] S. J. Chen and C. L. Hwang, *Fuzzy multiple attribute decision making methods. In Fuzzy multiple attribute decision making: Methods and applications*. Berlin, Heidelberg: Springer Berlin Heidelberg, 1992.

[72] R. K. Shukla, D. Garg, and A. Agarwal, "An integrated approach of fuzzy AHP and fuzzy TOPSIS in modeling supply chain coordination," *Production & Manufacturing Research*, vol. 2, pp. 415–437, 2014. https://doi.org/10.1080/21693277.2014.919886

[73] P. M. Podsakoff, S. B. MacKenzie, J.-Y. Lee, and N. P. Podsakoff, "Common method biases in behavioral research: A critical review of the literature and recommended remedies," *Journal of Applied Psychology*, vol. 88, no. 5, p. 879, 2003. https://doi.org/10.1037/0021-9010.88.5.879

[74] N. Kock, *Common method bias: A full collinearity assessment method for PLS-SEM. In: Latan, H., Noonan, R. (Eds.), Partial Least Squares Path Modeling*. Cham: Springer, 2017.

[75] T. Terzioglu, G. Polat, and H. Turkoglu, "Formwork system selection criteria for building construction projects: A structural equation modelling approach," *Buildings*, vol. 12, no. 2, p. 204, 2022. https://doi.org/10.3390/buildings12020204

[76] K. Gbongli, Y. Xu, K. M. Amedjonekou, and L. Kovács, "Evaluation and classification of mobile financial services sustainability using structural equation modeling and multiple criteria decision-making methods," *Sustainability*, vol. 12, no. 4, p. 1288, 2020. https://doi.org/10.3390/su12041288

[77] J. A. R. Santos, "Cronbach's alpha: A tool for assessing the reliability of scales," *Journal of Extension*, vol. 37, pp. 1-5, 1999.

[78] J. F. Hair, W. C. Black, B. J. Babin, R. E. Anderson, and R. L. Tatham, *Multivariate data analysis: Global edition*, 7th ed. Upper Saddle River: Pearson Education, 2009.

[79] J.-M. Becker, J.-H. Cheah, R. Gholamzade, C. M. Ringle, and M. Sarstedt, "PLS-SEM's most wanted guidance," *International Journal of Contemporary Hospitality Management*, vol. 35, no. 1, pp. 321-346, 2023. https://doi.org/10.1108/ijchm-04-2022-0474

[80] M. Sarstedt, J. F. Hair Jr, J.-H. Cheah, J.-M. Becker, and C. M. Ringle, "How to specify, estimate, and validate higher-order constructs in PLS-SEM," *Australasian Marketing Journal*, vol. 27, no. 3, pp. 197-211, 2019. https://doi:10.1016/j.ausmj.2019.05.003

[81] C. Crocetta *et al.*, "Higher-order PLS-PM approach for different types of constructs," *Social Indicators Research*, vol. 154, pp. 725-754, 2021. https://doi.org/10.1007/s11205-020-02563-w

[82] W. R. Dillon, K. A. Bollen, and J. S. Long, "Testing structural equation models," *Journal of Marketing Research*, p. 154, 1996. https://doi.org/10.2307/3152134

[83] L. t. Hu and P. M. Bentler, "Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives," *Structural Equation Modeling: A Multidisciplinary Journal*, vol. 6, no. 1, pp. 1-55, 1999. https://doi.org/10.1080/10705519909540118

[84] J. H. Steiger, "Structural model evaluation and modification: An interval estimation approach," *Multivariate Behavioral Research*, vol. 25, no. 2, pp. 173-180, 1990. https://doi.org/10.1207/s15327906mbr2502_4

[85] G. R. Franke, "Structural equation modeling with EQS and EQS/Windows," *Journal of Marketing Research*, vol. 32, no. 3, p. 378, 1995. https://doi.org/10.2307/3151989

[86] F. Khosravi and G. Izbirak, "A stakeholder perspective of social sustainability measurement in healthcare supply chain management," *Sustainable Cities and Society*, vol. 50, p. 101681, 2019. https://doi.org/10.1016/j.scs.2019.101681

[87] T. Maghsoudi, R. Cascon-Pereira, and A. Beatriz Hernández Lara, "The role of collaborative healthcare in improving social sustainability: A conceptual framework," *Sustainability*, vol. 12, no. 8, p. 3195, 2020. https://doi.org/10.3390/SU12083195

[88] P. Singh, "Lean in healthcare organization: An opportunity for environmental sustainability," *Benchmarking: An International Journal*, vol. 26, no. 1, pp. 205-220, 2019. https://doi.org/10.1108/bij-04-2018-0104

[89] D. S. Kc and C. Terwiesch, "Impact of workload on service time and patient safety: An econometric analysis of hospital operations," *Management Science*, vol. 55, no. 9, pp. 1486-1498, 2009. https://doi.org/10.1287/mnsc.1090.1037

[90] R. S. Zadeh, X. Xuan, and M. M. Shepley, "Sustainable healthcare design: Existing challenges and future directions for an environmental, economic, and social approach to sustainability," *Facilities*, vol. 34, no. 5/6, pp. 264-288, 2016. https://doi.org/10.1108/F-09-2013-0067

[91] R. S. Kerr, "Surgery in the 2020s: Implications of advancing technology for patients and the workforce," *Future Healthcare Journal*, vol. 7, pp. 46–49, 2020. https://doi.org/10.7861/fhj.2020-0001

[92] S. George and S. Elrashid, "The role of information technology and information sharing in pharmaceutical supply chain performance: Private hospitals' perspective," in *2021 International Conference on Decision Aid Sciences and Application (DASA)*, 2021: IEEE, pp. 601-606.

[93] B. Tsarfati and D. Cojocaru, "The importance of receiving training in computerized technology for nurses to maintain sustainability in the health system," *Sustainability*, vol. 14, no. 23, pp. 1-19, 2022. https://doi.org/10.3390/su142315958

[94] F. Pennestrì and G. Banfi, "The experience of patients in chronic care management: Applications in health technology assessment (HTA) and value for public health," *International Journal of Environmental Research and Public Health*, vol. 19, no. 16, p. 9868, 2022. https://doi.org/10.3390/ijerph19169868

[95] T.-C. T. Chen and M.-C. Chiu, "Evaluating the sustainability of smart technology applications in healthcare after the COVID-19 pandemic: A hybridising subjective and objective fuzzy group decision-making approach with explainable artificial intelligence," *Digital Health*, vol. 8, pp. 1-21, 2022. https://doi.org/10.1177/20552076221136381

[96] D. Manika, D. Gregory-Smith, V. K. Wells, L. Comerford, and L. Aldrich-Smith, "Linking environmental sustainability and healthcare: The effects of an energy saving intervention in two hospitals," *International Journal of Business Science and Applied Management*, vol. 11, no. 1, pp. 32-55, 2017.

[97] L. O'Mahony, K. McCarthy, J. O'Donoghue, S. P. Teeling, M. Ward, and M. McNamara, "Using lean six sigma to redesign the supply chain to the operating room department of a private hospital to reduce associated costs and release nursing time to care," *International Journal of Environmental Research and Public Health*, vol. 18, no. 21, p. 11011, 2021. https://doi.org/10.3390/ijerph182111011

[98] H. U. R. Khan, B. Usman, K. Zaman, A. A. Nassani, M. Haffar, and G. Muneer, "The impact of carbon pricing, climate financing, and financial literacy on COVID-19 cases: Go-for-green healthcare policies," *Environmental Science and Pollution Research*, vol. 29, no. 24, pp. 35884-35896, 2022. https://doi.org/10.1007/s11356-022-18689-y

[99] M. Nematollahi, S.-M. Hosseini-Motlagh, and J. Heydari, "Economic and social collaborative decision-making on visit interval and service level in a two-echelon pharmaceutical supply chain," *Journal of Cleaner Production*, vol. 142, pp. 3956-3969, 2017. https://doi.org/10.1016/j.jclepro.2016.10.062

[100] UN.ESCAP, "Promoting sustainable strategies to improve access to health care in the Asian and Pacific region: Discussion paper," Retrieved: https://hdl.handle.net/20.500.12870/3046. 2009.

[101] P. Tejativaddhana, D. Briggs, O. Singhadej, and R. Hinoguin, "Developing primary health care in Thailand: Innovation in the use of socio-economic determinants, sustainable development goals and the district health strategy," *Public Administration and Policy*, vol. 21, no. 1, pp. 36-49, 2018. https://doi.org/10.1108/pap-06-2018-005

[102] C. Zamiela, N. U. I. Hossain, and R. Jaradat, "Enablers of resilience in the healthcare supply chain: A case study of US healthcare industry during COVID-19 pandemic," *Research in Transportation Economics*, vol. 93, p. 101174, 2022. https://doi.org/10.1016/j.retrec.2021.101174

[103] A. St John, M. O'Kane, R. Christenson, P. Jülicher, M. Oellerich, and C. P. Price, "Implementation of medical tests in a value-based healthcare environment: A framework for delivering value," *Clinica Chimica Acta*, vol. 521, pp. 90-96, 2021. https://doi.org/10.1016/j.cca.2021.07.004

Appendix A. Sustainable healthcare supply chain attributes for patient safety.

Table A1.
SHSC attributes and references.

Dimension	Attributes	Definition
Social	SC1 health and safety	Prioritize the safety of employees, both in terms of physical and mental health, by promoting a secure workplace environment to prevent harm. Additionally, take measures to reduce the occurrence of hazardous incidents related to substandard medical products.
	SC2 skills, knowledge, and training	Enhance the proficiency and knowledge of healthcare practitioners through training to improve work efficiency, ultimately ensuring safer treatments and reducing the risk of life-threatening complications for patients.
	SC3 quality of care	Prevent the improper use of care, deliver care promptly, and ensure equitable access to care.
	SC4 employment	Emphasizes the efficiency of healthcare workers, their job satisfaction, work-life balance, overall well-being, and the benefits offered to them.
	SC5 equity	Prioritizes equal opportunities, diversity promotion, fairness, and fulfilling basic needs to sustain a satisfactory quality of life, eradicate gender bias, and diminish discrimination.
	SC6 clinical process efficiency	Ensure that both patients' and healthcare workers' needs are promptly met and that clinical activities provide excellent value for money.
	SC7 support process efficiency	Focuses on the procedures necessary for executing support activities within healthcare, such as imaging diagnostics, laboratory services, and inventory management.
	SC8 Collaboration	Promoting communication across the supply chain among stakeholders to uphold and enhance the quality of patient care.
Environmental	EV1 waste management	Ensuring proper medical waste management in healthcare facilities to minimize the environmental impact.
	EV2 green material	Encouraging the adoption of biodegradable and recyclable materials in medical products to reduce waste and mitigate the risk of pollution and contamination.
	EV3 energy efficiency	Encouraging the utilization of renewable energy sources like solar, wind, and geothermal power, decreasing reliance on fossil fuels, and minimizing the carbon footprint of healthcare operations.
	EV4 healthcare facility design	Encouraging the adoption of recyclable materials in construction for buildings and furnishings, decreasing reliance on non-renewable energy during construction, and prioritizing the design of healthcare facilities with a focus on the safety and security of both patients and practitioners.
Economic	EC1 financial	Ensure the availability of sufficient financial resources while simultaneously minimizing overall costs and maximizing revenue growth for the organization.
	EC2 process efficiency	The firm's capacity to convert diverse resources into value-added outputs while enhancing patient and healthcare worker safety by mitigating the risks associated with supply chain disruptions.
	EC3 marketing	The firm's capability to craft a distinctive competitive profile and establish a robust brand awareness and reputation.
	EC4 relationship management	The capacity to communicate efficiently and foster strong relationships among stakeholders, resulting in supply chain enhancements through information

Dimension	Attributes	Definition
		sharing and collaboration.
	EC5 service efficiency	The capacity to promptly respond to patient demand and deliver healthcare services, products, and equipment, thereby leading to enhanced patient outcomes.
	EC6 leadership and governance	Offering crucial guidance, supervision, and accountability by removing ambiguity in decision-making and furnishing the firm with clear directives.
Technology	TE1 information management	The capability to recognize and mitigate risks that could lead to supply chain disruptions, while also encouraging stakeholders to share and contribute data for tracking and traceability among supply chain participants.
	TE2 cybersecurity	The capacity of the healthcare organization to safeguard against cyber-attacks and guarantee patient safety. It involves promoting measures to secure critical firm data, including patient information, Electronic Medical Records (EMRs), and confidential hospital financial data.
	TE3 transparency and traceability	The capability to establish trust and credibility among supply chain stakeholders, while also advocating for track and traceability to validate the supply chain from upstream to downstream, thus mitigating risks and potential harm to patients.
	TE4 healthcare innovation	Strives to assist firms in gaining a competitive edge through innovation, with the goal of bolstering the healthcare supply chain and enhancing safety and efficiency in both clinical and non-clinical operations.